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ASSESSMENT OF INDUSTRIAL HAZARDOUS WASTE PRACTICES, STORAGE AND PRIMARY BATTERIES INDUSTRIES

VERSAR, INCORPORATED

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This report, which covers battery manufacturing operations, is one of a series of several studies which examine land-destined wastes from selected industries. The battery industry is divided into two groups by the Bureau of Census: Standard Industrial Classification (SIC) 3691 Storage Batteries (such as lead-acid automobile batteries) and SIC 3692 Primary Batteries (such as carbon-zinc flashlight batteries). The battery industry was studied because heavy metals such as mercury, cadmium, zinc, and lead are used in some of its manufacturing processes. These metals can be toxic in certain concentrations and forms. The potentially hazardous wastes destined for land disposal from the battery industry consist of industrial processing wastes, reject cells, and sludges from water pollution control devices. The amount of sludges destined for land disposal is expected to experience a large short term increase as water effluent guidelines are implemented. The impact of water effluent guidelines on land disposal of wastes is the largest single factor in determining future trends for this industry.

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Storage Batteries
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Sludges
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Cadmium
Mercury
Zinc
Chromium
Landfills
Disposal Technology
Disposal Costs

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1.0 INTRODUCTION

This report is the result of a study commissioned by the U.S. Environmental Protection Agency to assess "Industrial Hazardous Waste Practices--Storage and Primary Batteries Industries". Concurrently, the U.S. EPA is pursuing similar studies of other industry categories. This program is intended to provide the U.S. EPA with detailed and pertinent information on the generation, management, treatment, disposal, and costs related to wastes considered to be "potentially hazardous". Such information will be used by the U.S. EPA in developing guidelines or standards for the management of hazardous wastes.

This report contains the essential elements of the technical information in four major sections:

(a) Section 4.0 — Industrial Characterization

Characterizes the industry with regard to the number, location, size, and production of manufacturing establishments;

(b) Section 5.0 — Waste Characterization

Identifies and quantifies those hazardous wastes which are or will be generated by the battery manufacturing industry;

(c) Section 6.0 — Treatment and Disposal Technology

Describes current practices for treatment and disposal of hazardous wastes and determines the control technologies which might be applied to reduce potential hazards presented by these wastes upon disposal; and

(d) Section 7.0 — Cost Analysis

Estimates the cost and control technology implementation.

The individual elements of each of these are presented in detail in their respective sections of this report.

Throughout this report, wherever the terms "hazardous wastes" or "potentially hazardous wastes" are used it should be kept in mind that no final judgments are intended as to such classification. It is recognized and understood that additional information will be required as to the actual fate of such materials in a given "disposal" or "management" environment, before a final definition of "hazardous waste" evolves and is used. As an example, for certain of the waste streams identified in this report the U.S. EPA is currently supporting other studies designed to investigate leaching characteristics in various soil and moisture conditions.

2.0 EXECUTIVE SUMMARY

This report, which covers battery manufacturing operations, is one of a series of several studies which examine land-destined wastes from selected industries. The battery industry is divided into two groups by the Bureau of Census: Standard Industrial Classification (SIC) 3691 Storage Batteries (such as lead-acid automobile batteries) and SIC 3692 Primary Batteries (such as carbon-zinc flashlight batteries). The battery industry in the U.S. is relatively small. The industry consists of 262 plants, employs approximately 30,000 people and the value of products shipped amounts to $1.3 billion a year.

The battery industry was studied because heavy metals such as mercury, cadmium, zinc and lead are used in some of its manufacturing processes. These metals can be toxic in certain concentrations and forms.

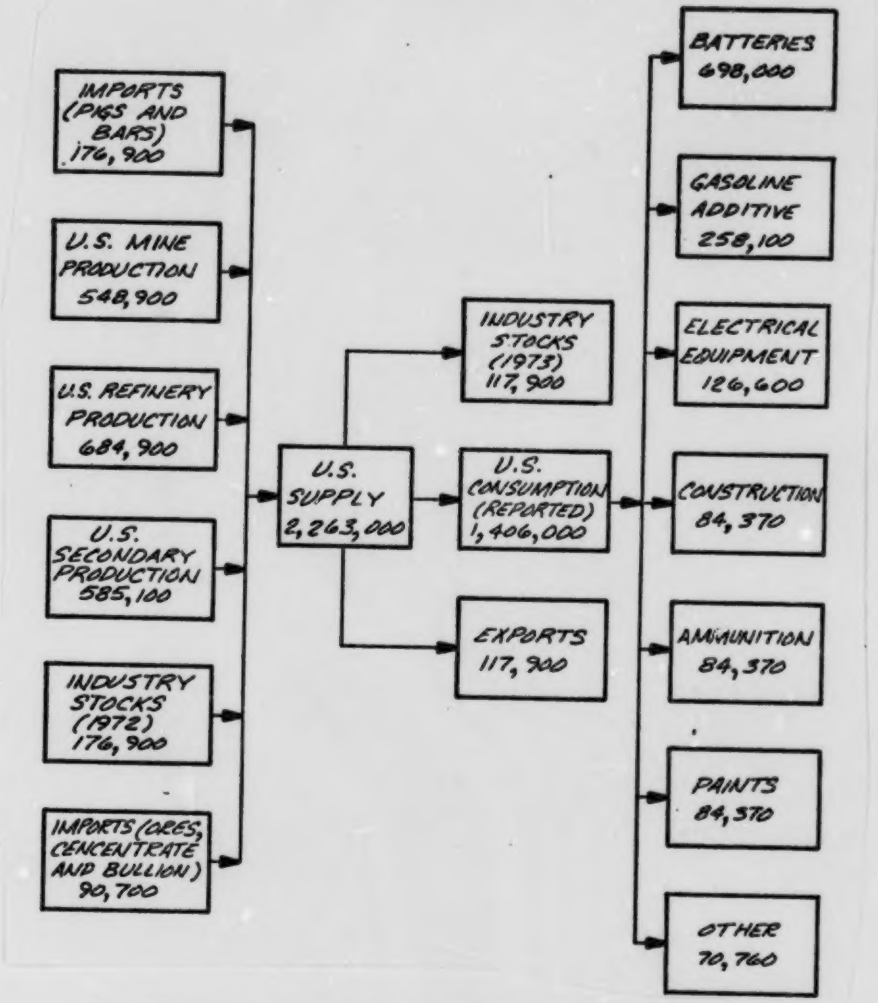
Large quantities of lead, cadmium, zinc, and mercury are used in battery manufacture and thus appear in the wastes produced by the industry, though they are present in only 5% of the wastes destined for land disposal and in low concentrations. The amounts of heavy metals which are reported by the U.S. Bureau of Mines (1973) for battery production in the U.S. are 698,038 kkg lead (50% of U.S. consumption), 848.3 kkg cadmium (15% of U.S. consumption), 408.2 kkg mercury (22% of U.S. consumption), and 27,210 kkg zinc (20% of U.S. consumption). The production and consumption of these metals in the U.S. are shown in flow chart form in Figures 1 through 4.

The land destined wastes from the battery industry contain a small percentage of heavy metals compared to the industry's total consumption. Only 0.007% of the total lead used by these industries is lost as waste, while 0.3% of the total cadmium, 0.5% of the total mercury, and 1.5% of the total zinc are lost.

There are 219 plants producing storage batteries, with 202 of these producing lead-acid batteries. These plants are located throughout the continental U.S. with the exception of a few states in the North West Central, North Mountain, and North North East regions. Thus, the geographical distribution of wastes from these plants is relatively widespread.

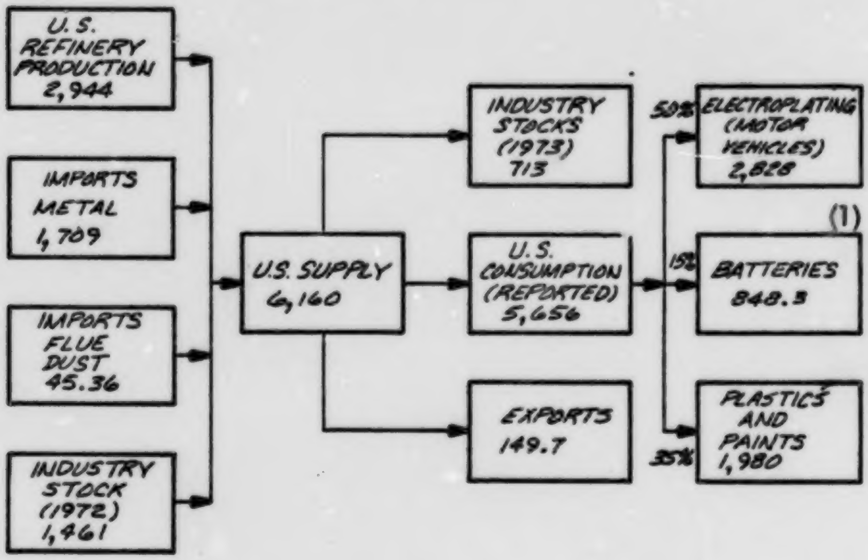
There are a relatively few plants in the primary battery industry, only 44; thus, the distribution of waste materials is concentrated in a relatively small number of locations primarily in the North East Central, North East, and Middle Atlantic regions. For example, mercury batteries are manufactured in eight plants and seventeen plants manufacture batteries containing cadmium.

The potentially hazardous wastes destined for land disposal from the battery industry consist of industrial processing wastes, reject cells, and sludges from water pollution control devices. The amount of sludges destined for land disposal is expected to experience a large short term increase as water effluent guidelines are implemented. The impact of water effluent guidelines on land disposal of wastes is the largest single factor in determing future trends for this industry.


IMPORTS (PIGS AND BARS) 176,900
U.S. MINE PRODUCTION 548,900
U.S. REFINERY PRODUCTION 684,900
U.S. SECONDARY PRODUCTION 585,100
INDUSTRY STOCKS (1972) 176,900
IMPORTS (ORES, CENCENTRATE AND BULLION) 90,700
U.S. SUPPLY 2,263,000
INDUSTRY STOCKS (1973) 117,900
U.S. CONSUMPTION (REPORTED) 1,406,000
EXPORTS 117,900
BATTERIES 698,000
GASOLINE ADDITIVE 258,100
ELECTRICAL EQUIPMENT 126,600
CONSTRUCTION 84,370
AMMUNITION 84,370
PAINTS 84,370
OTHER 70,760

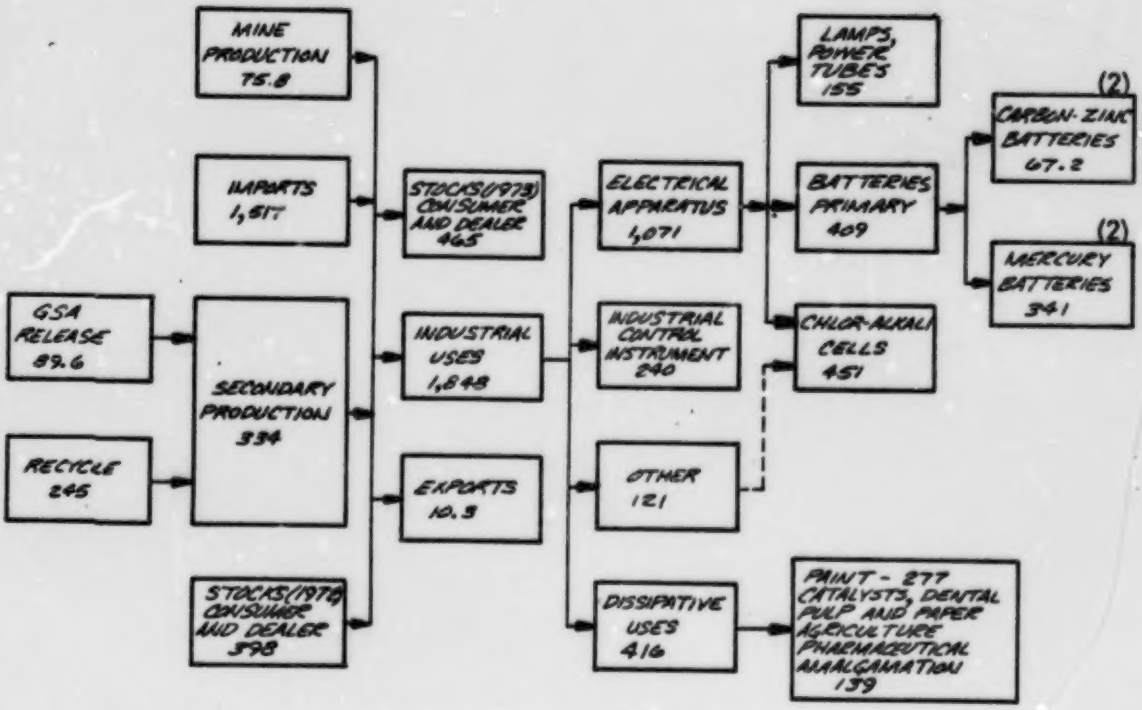
(1) All figures supplied by the Bureau of Mines 1974 Mineral Industry Surveys

Figure 1. Flow of Lead in the United States (1973)(1) Metric Tons/Year


U.S. REFINERY PRODUCTION 2,944
IMPORTS METAL 1,709
IMPORTS FLUE DUST 45.36
INDUSTRY STOCK (1972) 1,461
U.S. SUPPLY 6,160
INDUSTRY STOCKS (1973) 713
U.S. CONSUMPTION (REPORTED) 5,656
EXPORTS 149.7
50%
ELECTROPLATING (MOTOR VEHICLES) 2,828
(1)
15%
BATTERIES 848.3
35%
PLASTICS AND PAINTS 1,980

(1) Includes Ni-Cd and Ag-Cd batteries.
(2) All figures supplied by Bureau of Mines, Mineral Industry Surveys, 1974.

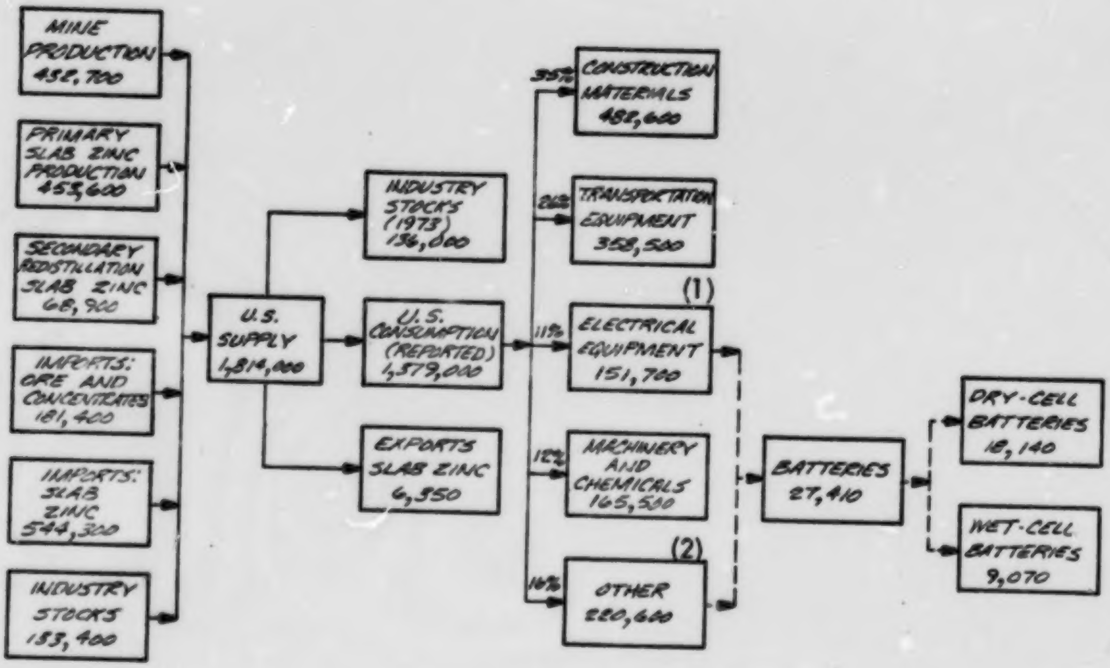
Figure 2. Flow of Cadmium in the United States (1973)(2)
Metric Tons/Year


MINE PRODUCTION 75.8
IMPORTS 1,517
GSA RELEASE 89.6
RECYCLE 245
SECONDARY PRODUCTION 334
STOCKS(1972) CONSUMER AND DEALER 398
STOCKS(1973) CONSUMER AND DEALER 465
INDUSTRIAL USES 1,848
EXPORTS 10.3
ELECTRICAL APPARATUS 1,071
INDUSTRIAL CONTROL INSTRUMENT 240
OTHER 121
DISSIPATIVE USES 416
LAMPS, POWER TUBES 155
BATTERIES PRIMARY 409
CHLOR-ALKALI CELLS 451
PAINT - 277
CATALYSTS, DENTAL
PULP AND PAPER
AGRICULTURE
PHARMACEUTICAL
AMALGAMATION
139
(2)
CARBON-ZINC BATTERIES 67.2
(2)
MERCURY BATTERIES 341

(1) Basic Data Supplied by Bureau of Mines 1974 Mineral Industry Survey.

(2) Versar estimate.

Figure 3. Flow of Mercury in the United States (1973)(1)
Metric Tons/Year


MINE PRODUCTION 452,700
PRIMARY SLAB ZINC PRODUCTION 453,600
SECONDARY REDISTILLATION SLAB ZINC 68,900
IMPORTS: ORE AND CONCENTRATES 181,400
IMPORTS: SLAB ZINC 544,300
INDUSTRY STOCKS 133,400
U.S. SUPPLY 1,814,000
INDUSTRY STOCKS (1973) 136,000
U.S. CONSUMPTION (REPORTED) 1,379,000
EXPORTS SLAB ZINC 6,350
35%
CONSTRUCTION MATERIALS 482,600
26%
TRANSPORTATION EQUIPMENT 358,500
(1)
11%
ELECTRICAL EQUIPMENT 151,700
12%
MACHINERY AND CHEMICALS 165,500
(2)
16%
OTHER 220,600
BATTERIES 27,410
DRY-CELL BATTERIES 18,140
WET-CELL BATTERIES 9,070

(1) Includes electrical transmission equipment, household appliances and communication equipment.

(2) Includes rolled zinc, lithographic plates, jewelry, stationary and decorative applications.

(3) All figures supplied by the Bureau of Mines 1974 Mineral Industry Surveys.

Figure 4. Flow of Zinc in the United States (1973)(3)
Metric Tons/Year

The wastes from the two categories of batteries differ greatly. Land-destined wastes from the storage battery industry (SIC 3691) consist largely of sludges from water effluent treatment along with a much lesser amount of rejected and scrap batteries. The greatest volume of potentially hazardous waste stems from lead-acid battery wastewater treatment sludges. Wastes from the primary battery industry (SIC 3692) are almost exclusively batteries rejected by quality control procedures. For primary batteries, the waste volume is small (about 1% of production), but the concentration of the potentially hazardous portion of the waste is larger than that for the storage batteries.

Table 1 summarizes the quantities of potentially hazardous materials (dry basis) and total waste streams (wet basis) destined for land disposal from the production of storage and primary batteries at the current time period and future projections for 1977 and 1983.

The storage battery industry (SIC 3691) currently disposes of 47.3 kkg of potentially hazardous constituents on land in a total waste stream of 9,235 kkg consisting of water effluent treatment sludges and rejected and scrap cells. Projections for 1977 for land disposal indicate that these figures will grow to 467 kkg of hazardous constituents contained in a total waste stream of 162,800 kkg. By 1983, land disposal of hazardous wastes will increase to 625 kkg in a total waste stream of 207,700 kkg.

The greatest amount of wastes destined for land disposal from this industry stems from lead-acid battery production. A large increase in hazardous waste for 1977 and 1983 is projected on the basis of future wastewater treatment guidelines. These projections were based on information obtained from industry on future growth of the industry along with possible changes in the wastewater treatment area, which will affect the amount of wastes destined for land.

The primary battery industry (SIC 3692) currently disposes of 448 kkg of potentially hazardous constituents in a total waste stream of 1,202 kkg as primarily rejected and scrap cells together with water effluent treatment sludges and furnace residues. By 1977, projections indicate that 514 kkg of hazardous constituents in a total waste stream of 1,500 kkg will be destined for land. By 1983, projections indicate that 502 kkg of hazardous constituents in a total waste stream of 1,350 kkg will be land disposed. The decrease of wastes going to land from 1977 to 1983 is due to projections concerning recovery of valuable scrap from the waste stream and a projected decrease in hazardous wastes from mercury cell production.

The wastes from battery production are generally not water soluble, and would normally have only minimal migration in a landfill environment. However, solubility varies greatly with small changes in pH, and pH varies in soils, ground-

Table 1. Battery Production Hazardous Wastes(1)

Category and Process SIC 3691 Storage Batteries	WASTE STREAM AND HAZARDOUS CONSTITUENTS	QUANTITY (kkg) Hazardous Constituents (Dry)			Total Waste Stream (Wet)		
		Present	1977	1983	Present	1977	1983
(a) Lead-Acid	(1) Wastewater Effluent Treatment-Sludge (lime or caustic) - containing suspended lead, lead sulfate, and lead hydroxide or calcium sulfate sludge containing lead.	33.1	447.6	609.4	9,217	162,756	207,683
(b) Nickel-Cadmium	(2) Wastewater Effluent Treatment Sludge - containing cadmium hydroxide and nickel hydroxide.	10.9	15.6	15.6	31.0	44.5	44.7
	(3) Rejected and Scrap Cells - containing cadmium and nickel.	3.3	3.7	0	4.6	5.3	0
(c) Cadmium-Silver Oxide	(4) Wastewater Effluent Treatment Sludge - containing cadmium hydroxide and silver oxide (reclaimed).	0	0	0	0	0	0
	(5) Rejected and Scrap Cells - containing cadmium-silver oxide (reclaimed).	0	0	0	0	0	0
(d) Zinc-Silver Oxide	(6) Rejected and Scrap Cells - containing zinc oxide-hydroxide, silver oxide, and mercury (reclaimed).	0	0	0	0	0	0
	TOTAL	47.3	466.9	625.0	9,253	162,806	207,728

Category and Process SIC 3692 Primary Batteries	WASTE STREAM AND HAZARDOUS CONSTITUENTS	QUANTITY (kkg) Hazardous Constituents (Dry)			Total Waste Stream (Wet)		
		Present	1977	1983	Present	1977	1983
(a) Carbon-Zinc	(1) Rejected and Scrap Batteries- containing mercury and zinc.	390.0	410.0	389.8	959.2	1,121	958.8
(b) Air Cell	(2) Rejected and Scrap Batteries- containing mercury and zinc.	1.4	1.6	1.7	47.2	55.2	57.4
(c) Alkaline-Manganese	(3) Rejected and Scrap Batteries- containing mercury and zinc.	23.9	28.0	29.1	140.9	164.7	171.3
(d) Mercury	(4) Scrap Batteries and Furnace Residue - containing mercury and zinc.	10.7	5.3	5.2	15.1	7.5	7.4
(e) Weston Mercury Cell	(5) Rejected and Scrap Batteries - containing mercury, mercurous sulfate, cadmium-mercury, and cadmium sulfate.	0.004	0	0	0.09	0	0
(f) Magnesium-Carbon	(6) Wastewater Effluent Treatment Sludge - containing trivalent chromium-carbonate-hydroxide.	10.1	47.8	47.8	25.2	119.4	119.4
(g) Zinc-Silver Oxide	(7) Rejected and Scrap Batteries-containing zinc and mercury (reclaimed).	0	0	0	0	0	0
(h) Lead Acid Reserve	(8) Rejected and Scrap Batteries-containing lead and nickel.	11.8	21.4	28.6	13.6	24.7	33.0
	(9) Wastewater Treatment Sludge - containing nickel and lead.	0.1	0.2	0.3	0.3	0.6	0.8
(i) Magnesium Reserve Cells	(10) Rejected and Scrap Batteries- containing silver chloride (reclaimed) or copper chloride	0	0	0	0	0	0
	TOTAL	448.0	514.4	502.5	1,202	1,493	1,348

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(1) For discussion of rationale and selection, see Section 5.4.3

waters, and necessarily in landfill environments. For this reason those wastes containing heavy metals in any form or concentration have been considered potentially hazardous for this report due to the possibility of leaching into surface or groundwater.

The prevalent method of treatment and disposal for potentially hazardous wastes from the storage batteries industry is land storage of wastewater treatment sludges and reclaimation, where possible,of reusable heavy metals such as lead, nickel and cadmium scrap. The best available technology currently used for the wastes from this industry is a segregated landfill equipped with leachate collection and treatment. Disposal in secured landfills is considered an environmentally adequate level of technology for small volume wastes with a relatively large hazardous waste content. Disposal of large volume sludges with a lower hazardous waste content in approved disposal facilities, with leachate treatment and monitoring, is also considered environmentally adequate.

For the primary batteries industry, the prevalent method of treatment and disposal is disposal in a simple landfill. The best available technology currently used for the wastes from this industry is segregated landfill equipped with leachate monitoring. Disposal in secured landfills is considered an environmentally adequate technology for the small volume, relatively high levels of hazardous wastes from this industry. Approved and secured landfills are defined in the text.

The cost of disposing of the small volume wastes in secured landfills does not appear to have significant economic consequences to the industry. The only area where relatively large costs are involved is the disposal of calcium sulfate water treatment sludges containing lead from the lead-acid storage battery industry.

In terms of total quantities, larger amounts of mercury, cadmium, and zinc are disposed of as discarded used batteries by the consumer than from manufacturers. However, each plant typically disposes of solid waste at one location, which increases the concentration and the potential for migration of hazardous materials at that location. The study of disposal of used batteries by consumers was not within the scope of this report.

3.0 DESCRIPTION OF THE STORAGE AND PRIMARY BATTERIES INDUSTRIES

3.1 Introduction

The products of the industry covered in this report are listed under two categories in the Standard Industrial Classification (SIC) Manual. These are SIC 3691, Storage Batteries, and SIC 3692, Primary Batteries, Dry and Wet. The production and other overall statistics of the industry grouped by codes are published by the Bureau of the Census, U. S. Department of Commerce, in the Census of Manufactures, Industry Series. Much of the information presented in this overall industry characterization is from the Preliminary Report, 1972 Census of Manufactures which is the most recent one available. Other sources of information were the individual battery producers.

3.2 Economic Structure and Products of the Storage and Primary Batteries Industries

In 1972, the value of products shipped and miscellaneous receipts of establishments classified in the SIC 3691 Storage Batteries Industry amounted to $960 million, and represents an increase of 66% over the 1967 total. The value added by manufacture was $474 million in 1972 — 83% above value added in 1967. Average employment in the industry increased by 14% from 1967 making a total of 22,000 employees in 1972.(1)* A general statistical description of the SIC 3691 Storage Batteries Industry by geographical areas is shown in Table 2, and the types of products, quantities and value for the industry are shown in Table 3.

For the SIC 3692 Primary Batteries Industry, the value of products shipped and miscellaneous receipts amounted to $348 million, an increase of 13% over the 1967 total. The value added by manufacture at $222 million in 1972 was 18% above the value added in 1967. The average employment in the industry showed a decrease of 24% from 1967 to a total of 8,400 employees in 1972. (2) A general statistical description of the SIC 3692 Primary Batteries Industry by geographical area is shown in Table 4 and the types of products, quantities and value for the Primary Batteries Industry are given in Table 5.

3.3 Storage Batteries Industry (SIC 3691) Products and Processes

In the SIC 3691 category over 95% of the batteries produced are lead-acid storage cells, nickel-cadmium storage cells, cadmium-silver storage cells, or zinc-silver storage cells.

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*Figures in parentheses refer to References in Section 8.0

Table 2. SIC 3691, General Statistics, by Geographic Areas - 1972(1)

Geographic Area	Establishments		All Employees		Production Workers			Value Added By Manu-facture (million dollars)	Cost of Materials, fuels, etc. (million dollars)	Value of Industry Shipment (million dollars)	Capital Expendi-tures, New (million dollars)
	Total (number)	With 20 Employees or more (number)	Number (1,000)	Payroll (million dollars)	Number (1,000)	Man-Hours (millions)	Wages (million dollars)				
United States, Total	208	117	22.0	208.4	17.9	35.8	158.9	474.3	507.2	959.6	28.6
Middle Atlantic Division	30	19	4.5	45.0	3.5	7.1	34.3	115.2	97.3	209.0	4.4
New York	7	4	.3	3.0	.2	.5	2.2	3.7	8.4	11.8	(D)
New Jersey	8	5	1.2	11.9	1.0	1.9	9.7	28.2	26.0	53.7	(D)
Pennsylvania	15	10	3.0	30.0	2.3	4.8	22.3	83.2	62.8	143.4	2.8
East North Central Division	32	20	5.0	49.4	4.0	7.8	39.0	117.0	120.7	235.7	3.6
Ohio	4	3	.3	2.3	.2	.4	1.6	3.7	8.1	11.4	.4
Illinois	11	5	1.1	10.0	.8	1.6	7.2	26.1	33.2	58.4	.8
South Region	62	35	6.8	59.4	5.7	11.3	44.7	125.7	152.2	269.4	12.5
South Atlantic Division	28	16	3.4	28.6	2.8	5.6	21.2	63.0	67.8	127.1	4.5
Georgia	8	5	1.0	9.1	.9	1.8	7.2	24.9	25.1	49.3	1.3
Florida	10	5	1.4	11.4	1.2	2.4	8.3	22.2	21.0	40.9	2.3
East South Central Division	12	7	1.1	10.3	1.0	1.9	7.8	19.3	34.0	52.0	.7
Tennessee	6	3	.3	2.7	.3	.6	2.3	7.5	12.2	19.1	.2
West South Central Division	22	12	2.3	20.6	1.9	3.9	15.8	43.4	50.4	90.3	7.4
Texas	17	8	1.6	13.7	1.4	2.9	10.6	30.6	32.7	58.9	7.1
West Region	54	24	2.9	27.4	2.3	4.7	20.4	64.8	72.1	132.5	5.6
Mountain Division	6	3	.2	1.4	.1	.3	.8	3.2	2.6	5.5	.8
Pacific Division	48	21	2.7	25.9	2.2	4.5	19.6	61.6	69.6	127.0	4.7
Oregon	7	4	.4	3.5	.3	.6	2.4	7.6	10.9	18.0	.4
California	34	17	2.3	22.3	1.9	3.9	17.0	53.4	57.9	107.6	4.3

Table 3. SIC 3691, Type, Quantity and Value, Products -1972(1)

Product Code	Product	Unit of Measure	Quantity	Value (million dollars)
3691- --	Storage Batteries, Total	--	(X)	945.3
36911 --	Storage Batteries, SLI Type	--	(X)	696.2
	Motor vehicle batteries, including tractor, aircraft, and marine; starting, lighting, and ignition types, complete units:			
	Automobile, truck, farm tractor, and bus:			
	Automotive types (all types primarily designed to fit passenger cars, regardless of application):			
36911 13	For original equipment, 6 volt and 12 volt.	Million units,	11.8	131.0
	For replacement:			
	Wet:			
36911 21	6 volt...........................	do	2.2	25.0
36911 23	12 volt	do	18.0	210.9
	Dry charge:			
36911 27	6 volt	do	2.7	31.8
36911 28	12 volt	do	16.7	206.1
	Heavy-duty transport, motor coach and bus, and diesel starting batteries (excluding marine and railway diesel starting batteries):			
	For original equipment:			
36911 32	6 volt	do	.9	12.9
36911 35	12 volt	do	.6	10.3
	For replacement:			
36911 42	6 volt............................	do	1.0	14.3
36911 45	12 volt...........................	do	1.1	20.7
36911 51	Aircraft..............................	do	.1	3.9
36911 71	Marine................................	do	.2	3.3
36911 98	Other starting, lighting, and ignition type batteries, including motorcycle..........			
36911 00	Storage batteries, SLI type, n.s.k..........	--	(X)	25.9
36912 --	Storage Batteries, Other Than SLI Type, including Parts for Storage Batteries, All Types................................	--	(X)	225.6
	Motive power type:			
36912 11	Industrial truck type................	Million units	.7	63.9
36912 19	Other motive power type storage batteries, including mining and industrial locomotive, and railway....	do	1.0	18.4
36912 51	Communication storage batteries, including radio station, telephone, telegraph, and railroad signaling......................	--	(X)	30.3
36912 61	Railway diesel starting batteries.........	1,000 units	19.9	6.6
	Nickel-cadmium:			
	Sealed:			
36912 72	Batteries........................	Mil. batteries	11.7	31.1
36912 73	Cells............................	Million cells	33.2	(X)
	Vented:			
36912 75	Batteries........................	Mil. batteries	4.6	16.5
36912 77	Cells............................	Million cells	8.6	(X)
	Lead acid:			
36912 81	Batteries...........................	Mil. batteries	9.9	17.9
36912 83	Cells...............................	Million cells	(NA)	(X)
36912 98	Other storage batteries, including farm and emergency lighting, and railway air conditioning and car lighting............	1,000 units	426.7	17.6
36912 91	Parts and supplies for storage batteries....	--	(X)	22.3
36912 00	Storage batteries, other than SLI type, including parts for storage batteries, all types, n.s.k.	--	(X)	1.0
36910 00	Storage batteries for establishments with 10 employees or more........................	--	(X)	14.8
36910 02	Storage batteries for establishments with less than 10 employees........................	--	(X)	8.7

(X) Not applicable. (NA, Not available.

Table 4. SIC 3692 General Statistics, by Geographic Areas - 1972(2)

Geographic Area	Establishments		All Employees		Production Workers			Value Added By Manufacture (million dollars)	Cost of Materials, fuels, etc. (million dollars)	Value of Industry Shipment (million dollars)	Capital Expenditures, New (million dollars)
	Total (number)	With 20 Employees or more (number)	Number (1,000)	Payroll (million dollars)	Number (1,000)	Man-Hours (millions)	Wages (million dollars)				
United States, Total	49	32	8.4	64.8	6.8	13.6	46.6	221.9	130.7	348.3	7.3
North Central Region	17	13	4.0	30.5	3.3	6.4	22.3	98.2	57.1	153.3	3.2
Pacific Division	5	-	-	.1	-	-	.1	.3	.2	.4	-
California	5	-	-	.1	-	-	.1	.3	.2	.4	-

Table 5. SIC 3692, Type, Quantity and Value, Products - 1972(2)

Product Code	Product	Unit of Measure		Value (million dollars)
3692- --	Primary Batteries, Dry and Wet, Total.......	--	(X)	316.7
	Dry Cell (Leclanche Type), Except Military:			
	General purpose (6 inches or equivalent) 1.5 volts:			
36920 12	Single unit..........................	Mil. batteries	5.3	5.4
36920 16	Multiple unit........................	do		
	Flashlight cells (single cell only):			
36920 21	D size (standard and industrial).......	Mil. cells	370.3	51.1
36920 25	C size (medium).....................	do	669.4	149.6
36920 29	All other single flashlight cell batteries, including AA- and AAA-size penlight and N-size novelty.................	do	669.4	149.6
36920 31	Lantern and other multiple-cell batteries, including general purpose industrial RR-type emergency and other multiple cells..	Mil. batteries	669.4	149.6
	Radio A-B and C cells:			
36920 55	Portable radio and instrument batteries.	do	669.4	149.6
36920 58	All other radio A-B and C cells, including farm radio A-B packs, hearing aid cells, and photoflash batteries..........................	do	669.4	149.6
	Dry Cell, Except Leclanche Type and Military:			
36920 72	Mercury.............................	do	669.4	149.6
36920 76	Alkali..............................	do	208.9	59.9
36920 79	All other dry cells....................	do	208.9	59.9
36920 92	Wet Cell, Primary Batteries................	do	1.0	8.3
36920 92	Wet Cell, Military type, including general purpose 1.5 volts, standard flashlight, and portable radio types.....................	do	1.0	8.3
36920 95	Parts and supplies for primary batteries......	--	(X)	14.7
36920 00	Primary batteries, dry and wet, n.s.k., for establishments with more than 10 employees..	--	(X)	4.8
36920 02	Primary batteries, dry and wet, n.s.k., for establishments with less than 10 employees...	--	(X)	.6

(X) Not applicable. (NA) Not available.

For the sake of completeness, however, a description of the remaining battery types such as the nickel-iron (Edison) storage cell, the nickel-zinc storage cell, the silver-lead storage cell, the cadmium-mercury, and the zinc-mercury storage cell is given.

At the present time, a total of 132 companies are identified as producers of storage batteries. According to the Bureau of the Census, the number of plants involved in this activity in 1972 was 208, while this survey revealed 219 plants in current production. The geographic distribution of these facilities will be covered below according to the specific types of storage batteries produced, while process data, typical plant descriptions, and diagrams of the major operations in the battery manufacture will be treated in Section 5.0.

3.3.1 Lead-Acid Storage Battery

Two hundred and two plants are identified as primary producers of lead-acid storage batteries. In Regions I through X, the number of plants are 10, 10, 18, 35, 38, 23, 14, 3, 39, and 12, respectively, and the states having the highest concentration of plants are California, Florida, Illinois, Pennsylvania and Texas.

The lead-acid battery represents the type of storage cell in widest use. The majority of these cells are used either for starting or for lighting and ignition functions (SLI) in automotive and industrial applications. Whereas production plants in the past have been small and located close to their markets, the present trend is toward larger plants with an attendant increase in efficiency and capacity. The industry is expected to continue its normal growth rate of 4 to 5% over the next ten years. A marketing analyst for one of the big lead-acid battery producers feels that a high demand for this battery will continue through the year 2000. The production of over 50,000 electric or battery-powered cars is expected between 1978 and 1983, and maintenance-free batteries will be original equipment in at least 50% of U.S. passenger cars by about 1980. (3)

3.3.2 Nickel-Cadmium Batteries

The rechargeable nickel-cadmium battery is the storage cell in next widest use today. These cells are produced both in vented and sealed types, with sizes ranging from small button cells (less than 14 mm in diameter) to large rectangular cells of 113 mm in height, 91 mm in length and 38 mm wide.

There are two distinct types of nickel-cadmium cells — the pocket plate (Jungner type) cell and the sintered-plate cell. Industry sources have indicated that only a limited number of pocket plate type batteries are now being produced in the U.S., the major production having been transferred to the sintered plate cell.

Ten plants have been identified as producers of nickel-cadmium storage batteries, and only one state has more than one plant. There are three major producing companies in the nickel-cadmium battery field.

In recent years, the use of nickel-cadmium batteries has expanded into calculators, walkie-talkies, pacemakers, portable appliances,and tools. Calculators currently are the biggest market for the battery. The demand for nickel-cadmium batteries almost doubled in 1973, and should settle into an annual growth pattern of between 15 and 20% over the next few years (according to the director of marketing of one of the major producers). In addition to the new expanding field of application, the battery has a stable market in both the personal appliance field and in alarm systems and emergency lighting. To meet this growing demand, one company has doubled production capacity over 1972 and plans still further expansions in the future. Furthermore, recent battery research by another nickel-cadmium producer has yielded a nickel-cadmium cell (introduced in 1973) for portable garden and power tools and hobby equipment. This cell charges to 90% of its capacity in 15 minutes. (4)

The availability of cadmium, however, is a problem that is starting to concern this industry. With the probable depletion (in 1974) of the available cadmium supply from General Services Administration, increased imports and domestic production will be required and further price increases may be expected. (6, 7)

3.3.3 Cadmium-Silver Oxide Storage Cell

There are seven plants producing cadmium-silver oxide or zinc silver oxide secondary cells. The cadmium-silver cell was developed in the late 1950's to meet demands for a longer life battery that could stand as high a rate of discharge as the silver-zinc system. Since its inception, the cadmium-silver oxide cell has found many uses in satellites and other space applications. Recently and in spite of its generally higher cost, this cell has been used commercially in appliances, tools, and portable television sets. The types of batteries available include rectangular vented cells, sealed cyclindrical cells, and sealed button cells. This storage cell is a specialty battery and is only produced in limited quantities and, indeed, the high cost and limited availability of cadmium and silver are expected to inhibit expanded commercial use of this cell. The production is expected to grow at a nominal rate of 5% per year over the next 5 years.

3.3.4 Zinc-Silver Oxide Secondary Cell

This battery is also a specialty item produced primarily for military uses in limited quantities. The most valuable feature of the zinc-silver cell is its high energy density (which can be as much as 6 times that of the nickel cadmium cell). The high cost of this cell has restricted its use to military and aerospace applications where cost is of minor importance. The cells currently produced in the U.S. are either vented rectangular or sealed cylindrical type.

3.3.5 Other Secondary Batteries

Four plants in the U.S. produce secondary batteries other than those treated above, though some duplication of plants producing secondary batteries is obviously possible.

3.3.5.1 Iron-Nickel Oxide Alkaline Storage Cell (Edison)

The only manufacturer of this battery discontinued production in June 1974. However, this company has recently established connections with the International Nickel Company of Canada, so the production of the iron-nickel oxide alkaline storage cells may be resumed in the future.

The iron-nickel oxide storage cell was used mainly for motive power in industrial vehicles such as fork lift trucks, electric cranes, mine shuttle cars and locomotives, motorized hand trucks, and railroad switching locomotives. Other applications were in the lighting area; e.g., portable miners' lights and for emergency light. These batteries have largely been replaced by the lead-acid storage battery because it is less expensive to produce.

3.3.5.2 Nickel-Zinc Secondary Cell

Although this system was developed as early as 1899 and was used in limited quantities for lighting and motive power in the 1930's, new investigations of the system may again warrant its use in lighting and motive power applications. This cell is currently a limited production item.

3.3.5.3 Silver-Lead Secondary Cell

This cell was developed as a stable low voltage power source and is produced in small quantities chiefly for military use.

3.3.5.4 Mercury-Cadmium Secondary Cell

This cell is used as a low voltage power source and has the dual advantages of a long storage life at elevated temperatures and a relatively constant voltage under load. Most of the cells produced are of the button type and are used by the military in artillery fuses, fail-safe units, missiles,and satellites.

3.4 Primary Battery Industry (SIC 3692) Products and Processes

For the SIC 3692 category, the types of batteries produced include the carbon-zinc cell, the carbon-zinc air cell, the alkaline-manganese cell, the mercury Ruben and Weston cells, the magnesium-carbon cell, the zinc-silver cell, the lead reserve cell, and others. The above named cells comprise more than 95% of the merchant production of the SIC 3692 primary cells, though, again a description of batteries contained in the "other" category (such as the low temperature carbon-zinc cell, the zinc silver chloride cell, the magnesium reserve cell, the thermal cell, the nuclear cell, and the lithium cell) is also given.

Twenty-five companies have been identified as producers of primary batteries, with 43 plants engaged in the production activity. Maryland, North Carolina, and Wisconsin are the states with the greatest number of plants.

3.4.1 Carbon-Zinc Dry Cell

The forerunner of the present-day carbon-zinc cell was introduced by Georges Leclanche in 1866, and the first true dry cell was developed by Carl Gassner between 1886 and 1888. The carbon-zinc dry cell was the first practical portable power source and is still the most widely used when portability is the prime requisite. (5)

The Leclanche or carbon-zinc dry cell is the primary battery manufactured in the greatest quantity in the United States. Four general types of carbon-zinc cells are available from most battery manufacturers, and the four areas of application for these types are radio, general purpose, flashlight and photoflash, and heavy-duty industrial. The different cells vary in physical characteristics depending on their intended application, and the size of these cells ranges from the tiny button cell through cylindrical flashlight cells and flat cells used in transistorized equipment, to the 9 cm (6 inch) cell which weighs about one kilogram.

The total number of plants reported as producing carbon-zinc dry cells is 15.

3.4.2 Carbon-Zinc Air Cell

The carbon-zinc air cell utilizes an air-depolarized carbon cathode, zinc anodes, and a solid sodium hydroxide electrolyte, thereby differing greatly from the carbon-zinc dry cell.

The carbon-zinc air cell is used in portable transceivers, semaphore devices, highway flashing systems, lighthouses, railway signals, night vision devices, and satellite communications. Rectangular cells are produced in various sizes according to their application.

3.4.3 Alkaline Manganese Dioxide Dry Cell

The alkaline dry cell is marketed as a higher performance cell with higher cost than the carbon-zinc cell. This cell has found wide usage in flashlights, camera equipment, battery powered toys, radios, tape recorders, etc., since the alkaline cell yields an improved performance over carbon-zinc cells particularly in the area of heavy or continuous current drains. These cells are produced primarily in button and cylindrical configurations. Seven plants are presently reported to be producing alkaline batteries.

3.4.4 Mercury Cell Primary Batteries

The Ruben mercury cell is used as a power source for electric watches, hearing aids, cameras, electronic instruments, depth finders,and transceivers. It has also found uses as a secondary standard of voltage in regulated power supplies, radiation detection meters, portable potentiometers, electronic computers,and voltage recorders. Mercury cells exhibit the following desirable operational characteristics: (a) high energy for a given volume and weight; (b) long shelf life; (c) no recovery period needed during discharge; and (d) relatively constant voltage during discharge. The button and cylindrical cells are the primarily manufactured configurations. Due to environmental considerations the quantity of mercury cells produced is expected to decrease.

The Weston mercury cell is used exclusively as a voltage standard and is contained in a glass vessel. Eight plants make mercury cells.

3.4.5 Magnesium-Carbon Dry Cell

The magnesium-carbon dry cell has a longer storage life and can withstand heat better than the carbon-zinc dry cell. By far the greatest use of this cell is military, although some cells are used commercially in aircraft emergency systems and marine and mining operations. Three plants are reported as producers of magnesium-carbon batteries.

3.4.6 Zinc-Silver Oxide Dry Cell

Zinc-silver oxide cells are used in hearing aids, electronic instruments, photoelectric devices, electric watches, and as a reference voltage source. The cells are manufactured in button, cylindrical, and rectangular configurations. Twelve plants are reported as producers of the zinc-silver oxide dry cell.

3.4.7 Other Primary Batteries

There are 17 plants in the United States producing primary batteries of types other than those covered above. Duplication with other primary batteries is, again, an obvious possibility.

3.4.7.1 Lead Reserve Cell

The lead-acid reserve cell is one of a class of cells designated "reserve" because they are supplied to the user in a non-activated state. For example, the lead-acid reserve cell is produced with all the components in a dry or non-activated state. When the cell is ready to be used, an acid is released into the cell and within a short period of time the cell is activated to a ready state. The cell then continues to supply power until the electrochemical reactions have proceeded to completion. Thus, the battery is stored (hence the name reserve cell), activated, and used (once) until depleted.

The lead-acid reserve cell is a limited production item designed solely for military use. There are currently only two producers in the U.S., and its manufacture varies widely with military requirements. The average annual production of these batteries over the last ten years has been approximately 113,500 kg per year. (19)

3.4.7.2 Low Temperature Carbon-Zinc Dry Cell

This specialty battery is a limited production item which is produced in a fashion identical to that of the standard carbon-zinc dry cell with only the substitution of non-freezing electrolytes in place of the zinc and ammonium chloride.

The low temperature cell is used almost entirely in military applications, and the same four areas of application for carbon-zinc dry cells are applicable for the low temperature cell; i.e., radio, general purpose, flashlight and photoflash, and heavy-duty industrial.

3.4.7.3 Magnesium-Silver and Copper-Chloride Cells

The magnesium reserve cells are used commercially for life-jacket, life-raft and lifebuoy lights, signal flare initiators, radio distress-beacon power supplies, flare-path markers, portable hand lamps, flashing beacons, and divers' and frogmen's lights. Military usage (in addition to the above) includes depth-charge initiators and radio power supplies. Cylindrical cells and flat cells are most commonly manufactured, although the sizes and shapes of this cell vary widely according to its intended use.

3.4.7.4 Zinc-Silver Chloride Cell

Industry sources indicate that this cell is not currently being produced in the U.S.

3.5 Future Battery Industry Developments

A highly sought item in the battery field is a practical battery for electric-powered vehicles. There are many efforts underway in this area; one being a battery which stores chlorine as a hydrate (an ice-like compound formed by bubbling the gas through a liquid) and uses a zinc-carbon anode. The chlorine is released gradually as warm electrolyte is pumped over the chlorine hydrate. (4)

In various stages of development and use are a new generation of powerful lightweight batteries which deliver more power per unit mass. With improvements in the economy of their production and the safety in handling some of their hazardous ingredients, they could compete with the carbon-zinc and mercury batteries. Most of the efforts in powerful light-weight batteries are still in the development stage, but some of these new batteries are in use in military and limited commercial applications. (4)

A material which has been considered for battery use for the past ten years by a number of companies is lithium. However, its great reactivity is a drawback to its use. In the past few years a number of lithium batteries using non-aqueous electrolytes have been developed and one primary battery is now on the market. However, large-scale production of rechargeable lithium batteries requires further safety and reliability tests. A member of Argonne National Laboratory (which has been doing research on lithium batteries since 1969) does not expect any general use for power plant energy storage or electric-powered vehicles until 1980. One company has an organic lithium cell which is operational from -40° to 160° C. This cell has been available since January 1973, but has been used only in military communications equipment and in the U.S. Navy's Sonobuoy. The company does not expect the battery to be ready for commerical applications for several years.

Another company is now marketing a primary lithium organic battery in the U.S. The high interest in organic lithium batteries can be appreciated when their characteristics are examined; e.g., they deliver twice the current of ordinary cells, are expected to have very long shelf lives and energy densities of 95 watt-hours/lb. for typical models, compared with 19.5 for a carbon-zinc cell.

Solid-state materials (for example, lithium iodide) can be used where liquid electrolytes are impractical. The conductivity is greatly reduced and, though high voltages can be generated, only weak currents can be drawn. The solid-state batteries are among the most reliable of the new generation of batteries. When used for powering heart pacemakers, they require replacement only once every ten years — compared with every two years for the mercury cells now in use. Several companies have been marketing solid-state batteries in a range of 2 to 200 volts since January 1973 for research, medical electronics, and security-system applications. (4)

Molten-salt electrolyte lithium batteries deliver the greatest power but require high temperatures to keep the cells molten. For example, one lithium-sulfur cell does not function until it reaches 400° C. Generally, molten-salt cells of the rechargeable type are still in the experimental stage. Results to date indicate the cells could deliver up to seven times the power of conventional lead-acid storage batteries of similar weight and could operate 100 times longer on a single charge.

The improvements in performance of new battery systems both those developed recently and those still in the developmental stage — could have a considerable impact on the battery industry in the future. Unfortunately, the future environmental impact of the production of these batteries is difficult to assess due to the proprietary nature of these products and the obvious unwillingness of the producers to talk about quantities of production or the constituents of the cells.

3.6 Program Methodology

All information released by the industry for this project was done so on a voluntary basis. As a result, most manufacturers were not cooperative in supplying requested information, while others were cooperative. Although good information was gathered on most manufacturing processes, some processes were either highly proprietary or detailed information was simply not available.

3.6.1 Data Acquisition

The data needed for this study was obtained by four different methods. The first was by reviewing published information and data in the technical literature, trade journals, government reports, and technical surveys conducted by the industry associations. A complete list of references is presented in Section 8.0 of this report.

The second method involved trade association participation. The following three trade associations were contacted and all expressed a willingness to assist in the program:

Trade Association	Location
Battery Council International	Burlingame, California
Independent Battery Manufacturers Association, Inc.	Largo, Florida
National Electrical Manufacturers Association	New York, New York and Washington D. C.

The names of member companies who are producers of batteries in the SIC 3691 and 3692 categories were given to the Contractor by these trade associations. However, the trade associations left the degree of participation in the study up to the individual producers, and the degree of this participation ranged from none to full cooperation.

The third method of data acquisition was by personal visits by the contractor to battery manufacturing establishments and waste disposal sites. A better and more thorough understanding of the generation of wastes destined for land disposal from battery production was obtained through personal interviews.

The fourth method of data acquisition was by letter-request — sent to all known battery producers which were not contacted personally for information on the generation of hazardous wastes destined for land disposal from their operations.

The results of the overall methodology were generally fruitful in that information was obtained from 30 companies, representing 90% of the production of the SIC 3691 industry and 97% of the production of the SIC 3692 industry.

3.6.2 Data Analysis

The major tasks involved in the data analysis were:

(a) To review the collected data for consistency, sufficiency, and probable accuracy;

(b) To assemble the more reliable data elements into a data base sufficient to allow meaningful projections to be made; and

(c) To utilize the data base and subsequent waste factors to allow tabulation of wastes on a state by state, federal EPA region, and national basis.

For the SIC 3691 category, there is only a limited data base for the nickel-cadmium and "other" product categories. The estimated accuracy of the projections for these categories is ±40%. For the lead-acid product category of SIC 3691, the accuracy of the data base is estimated to be ±20%, however, since the hazardous wastes to land disposal projections were made on the basis of as yet unestablished water pollution guidelines, the accuracy of these projections cannot be estimated.

For the SIC 3692 category, there was a more complete data base for all product categories with the exception of zinc-silver oxide, magnesium-reserve and other miscellaneous cells. The accuracy of the projections for carbon-zinc, alkaline, mercury, magnesium-carbon, air cell, and Weston cell is estimated to be ± 15%. The accuracy of the data base for the other primary batteries is estimated to be ±40%. The accuracy of the data base and projections could be improved by the passage of legislation which would require manufacturers to divulge information concerning hazardous materials.

4.0 INDUSTRY CHARACTERIZATION

4.1 Introduction

The first phase of this assessment of hazardous waste practices for the storage and primary batteries industries involved a statistical characterization of the industry in terms of the number and location of manufacturing plants, a distribution of the size of the plants according to the number of employees, the age of the facilities, and the products produced for each category of the industry.

The industry categorization is by 4-digit SIC code classification. This gives two major categories:

SIC 3691 — Storage Batteries; and
SIC 3692 — Primary Batteries, Dry and Wet.

Figure 5 shows the product distribution for the two categories.

4.2 General Observations of the Industry

The storage and primary batteries industries as a whole have the following general characteristics:

(a) There are many diverse product types and processes;

(b) The sizes of companies vary from very large (one thousand employees) to very small (two to four employees);

(c) Many of the products and processes are highly proprietary;

(d) There is a lengthy development-production cycle to bring new products on the market;

(e) In consumer product lines, there is a great deal of cost competition among producers;

(f) There is a basic conservatism in the industry forproduct or process modification; and

(g) There are severe product quality constraints which prevent short term product or process modification.

SIC 3691 - STORAGE BATTERIES

TYPES - LEAD ACID
NICKEL-CADMIUM
ZINC-SILVER
CADMIUM-SILVER
OTHER - EDISON, SILVER-LEAD,
ZINC-MERCURY

SIC 3692 - PRIMARY BATTERIES

TYPES - CARBON-ZINC (LECLANCHE)
ALKALINE MANGANESE
MERCURY CELLS
MAGNESIUM-CARBON
SILVER OXIDE
OTHER - AIR CELLS,
RESERVE CELLS

Figure 5. Characterization of the Battery Industry

4.3 Statistical Characterization of SIC 3691 Storage Batteries

Tables 6 through 7 present pertinent data for the SIC 3691 category. The tables include the following state-by-state data partitions:

(1) number of establishments;
(2) establishment size grouping by number of employees;
(3) establishment age grouping;
(4) grouping by battery process type; and
(5) annual production by metric tons of batteries.

The total number of facilities producing batteries in the SIC 3691 group was found to be 219, and Figure 6 shows the geographical distribution of these establishments.

Table 6 — This table presents the following information:

(a) The number of storage battery manufacturing plants on a state-by-state and Federal region basis. Ref. - 1, 2, 10, 11, 12 and 14.

(b) The distribution of sizes, based upon number of employees, for the storage battery plants on a state-by-state and Federal region basis. Ref. - 1, 2 and 14.

(c) The distribution of ages for the storage battery plants on a state and regional basis. Ref. - 10, 11, 14 and 15.

(d) The number of manufacturing locations on a national basis producing three types of storage batteries; i.e., lead-acid, nickel-cadmium, and others. The "other" category includes storage batteries which are of limited production for specialized applications. Ref. - 1, 10, 11, 12 and 14.

Table 7 — This table shows the distribution of annual production of lead-acid, nickel-cadmium and other batteries on a state and regional basis. Information on the nickel-cadmium battery is based on 1972 Census Data and an estimate of distribution made by Versar. Information on "other" storage batteries (such as zinc-silver and cadmium-silver) is chiefly an estimate of distribution made by Versar based upon information from various sources. Ref. - 1, 10, 11, 14 and 15.

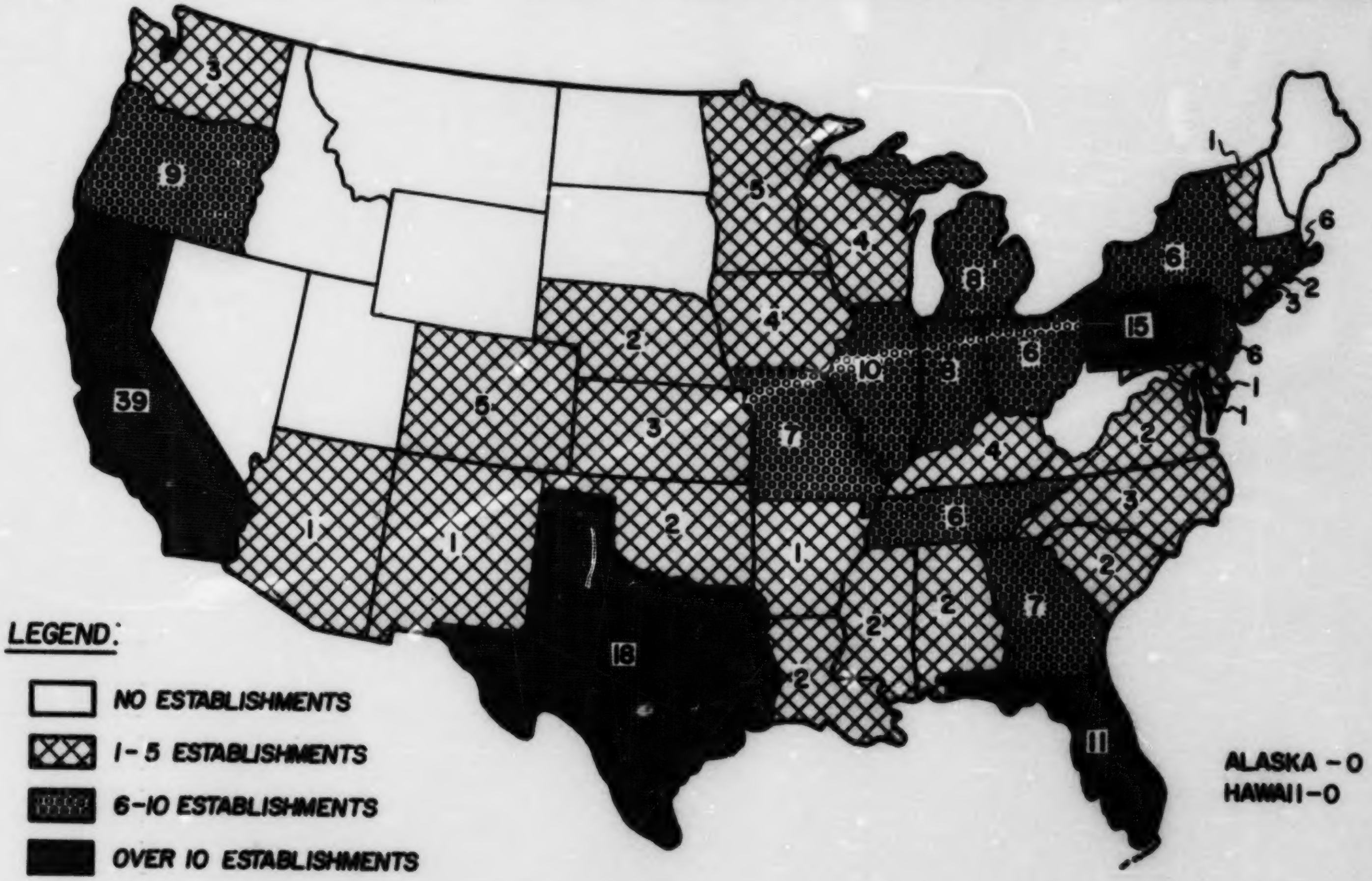
3
9
39
5
2
1
1
3
2
18
5
4
4
2
1
2
7
10
8
8
6
2
4
6
2
2
7
3
2
11
6
15
1
6
2
3
6
1
1
1
LEGEND:
NO ESTABLISHMENTS
1-5 ESTABLISHMENTS
6-10 ESTABLISHMENTS
OVER 10 ESTABLISHMENTS
ALASKA - 0
HAWAII - 0

Figure 6. SIC 3691 - Storage Batteries, Distribution of Establishments

Table 6 - Product Category - 3691 Storage Batteries

REGION/STATE	TOTAL	PLANT SIZE							PLANT AGE				PROCESS TYPE		
		A	B	C	D	E	F	G	H	I	J	K	L	M	N
IV ALABAMA	2	1	0	1	0	0	0	0	1	1	0	0			
X ALASKA	1	1	0	0	0	0	0	0	0	1	0	0			
IX ARIZONA	1	1	0	0	0	0	0	0	0	1	0	0			
VI ARKANSAS	1	0	1	0	0	0	0	0	0	0	1	0			
IX CALIFORNIA	39	21	4	4	9	1	0	0	5	30	4	0			
VIII COLORADO	5	1	0	3	1	0	0	0	1	3	1	0			
I CONNECTICUT	3	2	0	0	1	0	0	0	0	2	1	0			
III DELAWARE	1	0	0	0	0	1	0	0	0	1	0	0			
IV FLORIDA	11	5	1	3	1	0	1	0	1	9	1	0			
IV GEORGIA	7	1	0	3	2	1	0	0	0	7	0	0			
IX HAWAII	0	0	0	0	0	0	0	0	0	0	0	0			
X IDAHO	0	0	0	0	0	0	0	0	0	0	0	0			
V ILLINOIS	10	4	1	1	2	2	0	0	2	6	2	0			
V INDIANA	8	2	1	0	2	3	0	0	0	7	1	0			
VII IOWA	4	2	1	1	0	0	0	0	1	3	0	0			
VII KANSAS	3	0	1	0	1	0	1	0	0	3	0	0			
IV KENTUCKY	4	3	0	0	0	0	1	0	2	2	0	0			
VI LOUISIANA	2	1	1	0	0	0	0	0	0	2	0	0			
I MAINE	0	0	0	0	0	0	0	0	0	0	0	0			
III MARYLAND	1	1	0	0	0	0	0	0	0	1	0	0			
I MASSACHUSETTS	6	2	1	3	0	0	0	0	1	3	2	0			
V MICHIGAN	8	6	0	1	0	1	0	0	1	4	3	0			
V MINNESOTA	5	2	1	0	1	1	0	0	0	5	0	0			
IV MISSISSIPPI	2	0	1	0	1	0	0	0	0	2	0	0			
VII MISSOURI	7	2	2	0	1	2	0	0	1	5	1	0			
VIII MONTANA	0	0	0	0	0	0	0	0	0	0	0	0			
VII NEBRASKA	2	1	0	1	0	0	0	0	1	1	0	0			
IX NEVADA	0	0	0	0	0	0	0	0	0	0	0	0			
I NEW HAMPSHIRE	0	0	0	0	0	0	0	0	0	0	0	0			
II NEW JERSEY	6	2	0	0	1	2	1	0	0	4	2	0			
VI NEW MEXICO	1	1	0	0	0	0	0	0	0	1	0	0			
II NEW YORK	6	4	1	0	1	0	0	0	2	4	0	0			
IV NORTH CAROLINA	3	0	1	0	1	1	0	0	0	2	0	1			
VIII NORTH DAKOTA	0	0	0	0	0	0	0	0	0	0	0	0			
V OHIO	6	2	2	0	1	0	1	0	1	4	0	1			
VI OKLAHOMA	2	1	0	0	1	0	0	0	1	1	0	0			
X OREGON	9	4	1	2	2	0	0	0	1	8	0	0			
III PENNSYLVANIA	15	5	2	1	2	4	1	0	1	12	1	1			
I RHODE ISLAND	2	0	1	0	0	1	0	0	0	2	0	0			
IV SOUTH CAROLINA	2	0	0	0	1	1	0	0	0	2	0	0			
VIII SOUTH DAKOTA	0	0	0	0	0	0	0	0	0	0	0	0			
IV TENNESSEE	6	4	0	0	2	0	0	0	0	6	0	0			
VI TEXAS	18	11	0	1	3	2	1	0	3	14	0	1			
VIII UTAH	0	0	0	0	0	0	0	0	0	0	0	0			
I VERMONT	1	0	0	0	0	1	0	0	0	1	0	0			
III VIRGINIA	2	0	0	0	2	0	0	0	0	2	0	0			
X WASHINGTON	3	3	0	0	0	0	0	0	1	2	0	0			
III WEST VIRGINIA	0	0	0	0	0	0	0	0	0	0	0	0			
V WISCONSIN	4	2	0	1	0	0	1	0	0	2	1	1			
VIII WYOMING	0	0	0	0	0	0	0	0	0	0	0	0			
TOTAL US	219	98	24	26	39	24	8	0	27	166	21	5	202	10	8

KEY FOR SIZES

A	LESS THAN	20
B	BETWEEN	20 and 50
C	BETWEEN	50 and 100
D	BETWEEN	100 and 250
E	BETWEEN	250 and 500
F	BETWEEN	500 and 1000
G	GREATER THAN	1000

KEY FOR AGES

H	LESS THAN	5
I	BETWEEN	5 and 30
J	BETWEEN	30 and 50
K	GREATER THAN	50

KEY FOR PROCESSES & PRODUCTION

L	LEAD ACID
M	NICKEL CADMIUM
N	OTHER

A STATE BY STATE LISTING OF PROCESS TYPES CANNOT BE GIVEN TO AVOID DISCLOSURE OF INDIVIDUAL PLANTS

REGION	TOTAL	PLANT SIZE							PLANT AGE				PROCESS TYPE		
		A	B	C	D	F	F	G	H	I	J	K	L	M	N
REGION 1	12	4	2	3	1	2	0	0	1	8	3	0			
REGION 2	12	6	1	0	2	2	1	0	2	8	2	0			
REGION 3	19	6	2	1	4	5	1	0	1	16	1	1			
REGION 4	37	14	3	7	8	3	2	0	4	31	1	1			
REGION 5	41	18	5	3	6	7	2	0	4	28	7	2			
REGION 6	24	14	2	1	4	2	1	0	4	18	1	1			
REGION 7	16	5	4	2	2	2	1	0	3	12	1	0			
REGION 8	5	1	0	3	1	0	0	0	1	3	1	0			
REGION 9	40	22	4	4	9	1	0	0	5	31	4	0			
REGION 10	13	8	1	2	2	0	0	0	2	11	0	0			
TOTAL US	219	98	24	26	39	24	8	0	27	166	21	5	202	10	8

A REGIONAL LISTING OF PROCESS TYPES CANNOT BE GIVEN TO AVOID DISCLOSURE OF INDIVIDUAL PLANTS

TABLE 7.

SIC 3691, DISTRIBUTION OF ANNUAL PRODUCTION, LEAD-ACID, NICKEL-CADMIUM AND OTHER (1972, Production in Metric Tons)

REGION/STATE		Lead Acid	Nickel-Cadmium	Other
IV	Alabama	10,848	0	0
X	Alaska	537	0	0
IX	Arizona	534	0	0
VI	Arkansas	1,740	0	0
IX	California	150,622	0	11.4
VIII	Colorado	1,407	Combined with Iowa	90.8
I	Connecticut	9,666	0	0
III	Delaware	17,798	0	0
IV	Florida	22,682	Combined with Texas	59
IV	Georgia	46,206	0	0
IX	Hawaii	0	0	0
X	Idaho	0	0	0
V	Illinois	67,086	0	0
V	Indiana	97,702	0	0
VII	Iowa	5,499	283.3	0
VII	Kansas	35,037	0	0
IV	Kentucky	31,776	0	0
VI	Louisiana	2,277	0	0
I	Maine	0	0	0
III	Maryland	535	0	0
I	Massachusetts	9,257	Combined with N.J. & N.Y.	0
V	Michigan	49,042	0	0
V	Minnesota	21,611	Combined with Ohio	0
IV	Mississippi	10,333	0	0
VII	Missouri	13,146	0	0
VIII	Montana	0	0	0
VII	Nebraska	3,759	0	0
IX	Nevada	0	0	0
I	New Hampshire	0	0	0
II	New Jersey	64,447	Combined with Mass. & N.Y.	0
VI	New Mexico	536	0	0
II	New York	3,887	646.9	0
IV	North Carolina	14,477	0	99.9
VIII	North Dakota	0	0	0
V	Ohio	11,943	1,161.8	0
VI	Oklahoma	9,129	0	0
X	Oregon	25,610	0	11.4
III	Pennsylvania	133,124	0	4.5
I	Rhode Island	1,740	0	32.7
IV	South Carolina	30,075	0	0
VIII	South Dakota	0	0	0
IV	Tennessee	19,332	0	0
VI	Texas	93,191	1,913.6	0
VIII	Utah	0	0	0
I	Vermont	18,282	0	0
III	Virginia	17,185	0	0
X	Washington	1,610	0	0
III	West Virginia	0	0	0
V	Wisconsin	21,936	0	0
VIII	Wyoming	0	0	0
TOTAL		1,081,187	4,005.6	309.7
Region	I	38,945	Combined with Region II	32.7
	II	68,334	646.9	0
	III	168,645	0	4.5
	IV	185,730	Combined with Region VI	158.9
	V	269,320	1,161.8	0
	VI	106,874	1,913.6	0
	VII	57,441	Combined with Region VIII	0
	VIII	6,981	283.3	90.9
	IX	151,159	0	11.4
	X	27,757	0	0

4.4 Statistical Characterization of SIC 3692 Primary Batteries

Tables 8 and 9 present pertinent data for the SIC 3692 category. The tables include the following state-by-state data partitions:

(1) number of establishments;
(2) establishment size grouping by number of employees;
(3) establishment age grouping;
(4) grouping by battery process type; and
(5) annual production by number of batteries.

The total number of facilities producing batteries in the SIC 3692 group was found to be 43, and Figure 7 shows the geographical distribution of these facilities.

Table 8 — This table shows the following information:

(a) The number of dry and wet primary battery manufacturing plants on a state-by-state and Federal region basis. Ref. - 2, 12, 13 and 14.

(b) The distribution of sizes, based upon number of employees, for the primary battery plants on a state and regional basis. Ref. - 2, 13 and 14.

(c) The distribution of ages for the primary battery plants on a state and regional basis. Ref. - 14 and 15.

(d) The number of manufacturing locations on a national basis producing six types of primary batteries; i.e., carbon-zinc, alkaline, mercury, magnesium, silver and others. The "other" category includes primary batteries such as the air cells, magnesium and lead reserve cells,and solid electrolyte cells. These batteries are of limited production for special applications. Ref. - 2, 12 and 14.

Table 9 — This table shows the distribution of annual production of six types of primary batteries on a state and regional basis. The battery types covered include carbon-zinc, alkaline-manganese, mercury cell, magnesium, silver,and others. (This information is based upon 1972 Census data, aggregate data supplied by NEMA and industry sources with Versar estimates.) Ref. - 2, 15 and 16.

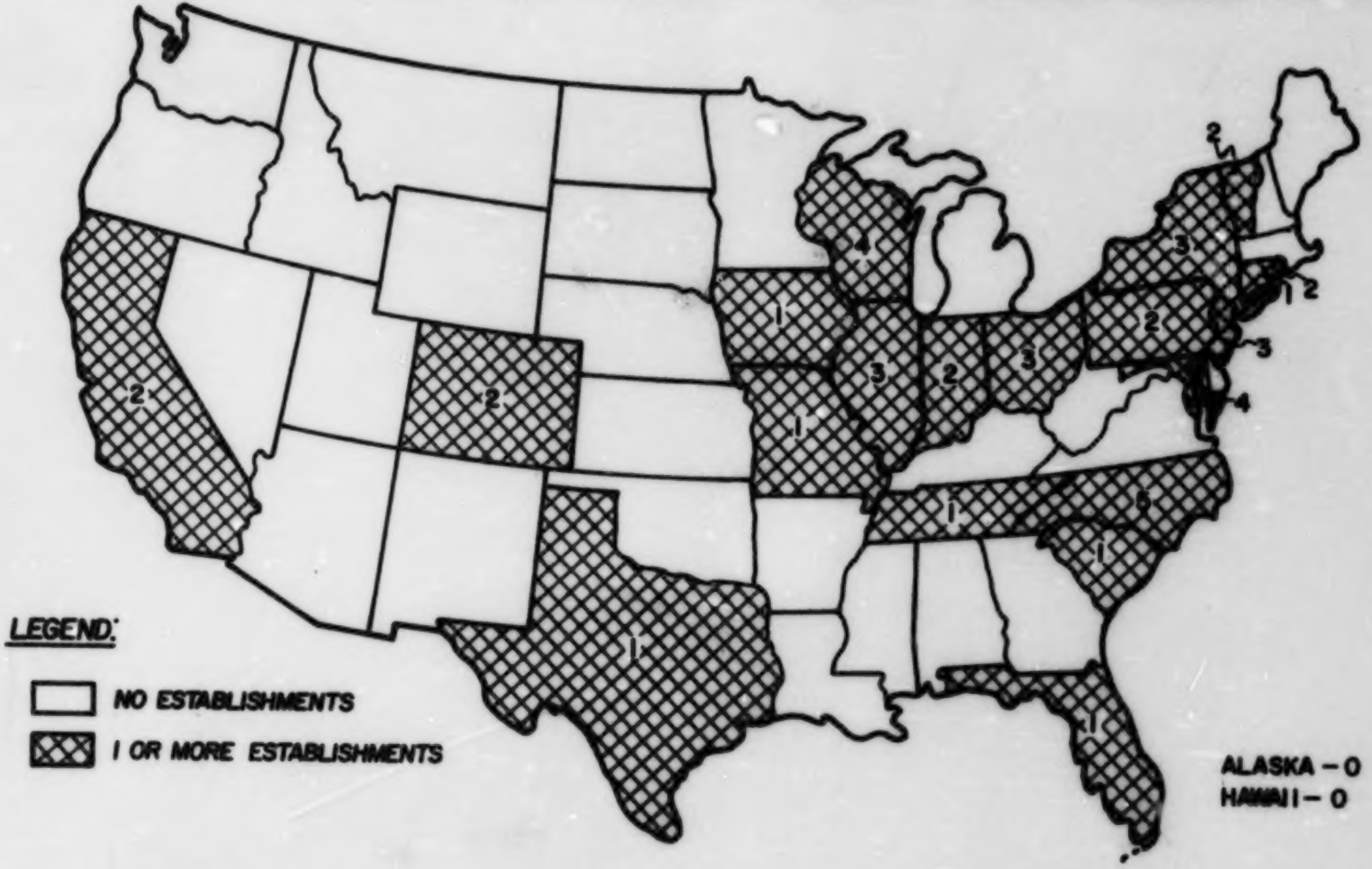
LEGEND:
NO ESTABLISHMENTS
I OR MORE ESTABLISHMENTS
ALASKA – 0
HAWAII – 0
2
2
1
1
1
4
3
2
3
2
3
2
1
2
3
4
1
5
1
1

Figure 7. SIC 3692 – Primary Batteries, Distribution of Establishments

Table 8 - Product Category - 3692 Primary Batteries

REGION/STATE	TOTAL	PLANT SIZE A	B	C	D	E	F	G	PLANT AGE H	I	J	K	PROCESS TYPE L	M	N	O	P	Q
IV ALABAMA	0	0	0	0	0	0	0	0	0	0	0	0						
X ALASKA	0	0	0	0	0	0	0	0	0	0	0	0						
IX ARIZONA	0	0	0	0	0	0	0	0	0	0	0	0						
VI ARKANSAS	0	0	0	0	0	0	0	0	0	0	0	0						
IX CALIFORNIA	2	2	0	0	0	0	0	0	1	1	0	0						
VIII COLORADO	2	0	0	2	0	0	0	0	0	2	0	0						
I CONNECTICUT	1	0	1	0	0	0	0	0	0	1	0	0						
III DELAWARE	0	0	0	0	0	0	0	0	0	0	0	0						
IV FLORIDA	1	0	0	0	1	0	0	0	0	1	0	0						
IV GEORGIA	0	0	0	0	0	0	0	0	0	0	0	0						
IX HAWAII	0	0	0	0	0	0	0	0	0	0	0	0						
X IDAHO	0	0	0	0	0	0	0	0	0	0	0	0						
V ILLINOIS	3	0	1	1	0	0	1	0	1	2	0	0						
V INDIANA	2	1	0	0	1	0	0	0	0	2	0	0						
VII IOWA	1	0	0	0	0	1	0	0	0	1	0	0						
VII KANSAS	0	0	0	0	0	0	0	0	0	0	0	0						
IV KENTUCKY	0	0	0	0	0	0	0	0	0	0	0	0						
VI LOUISIANA	0	0	0	0	0	0	0	0	0	0	0	0						
I MAINE	0	0	0	0	0	0	0	0	0	0	0	0						
III MARYLAND	4	1	1	2	0	0	0	0	1	2	1	0						
I MASSACHUSETTS	0	0	0	0	0	0	0	0	0	0	0	0						
V MICHIGAN	0	0	0	0	0	0	0	0	0	0	0	0						
V MINNESOTA	0	0	0	0	0	0	0	0	0	0	0	0						
IV MISSISSIPPI	0	0	0	0	0	0	0	0	0	0	0	0						
VII MISSOURI	1	0	0	0	0	1	0	0	0	1	0	0						
VIII MONTANA	0	0	0	0	0	0	0	0	0	0	0	0						
VII NEBRASKA	0	0	0	0	0	0	0	0	0	0	0	0						
IX NEVADA	0	0	0	0	0	0	0	0	0	0	0	0						
I NEW HAMPSHIRE	0	0	0	0	0	0	0	0	0	0	0	0						
II NEW JERSEY	3	1	0	0	1	1	0	0	0	2	1	0						
VI NEW MEXICO	0	0	0	0	0	0	0	0	0	0	0	0						
II NEW YORK	3	1	0	1	0	1	0	0	1	2	0	0						
IV NORTH CAROLINA	5	0	0	0	1	2	2	0	0	5	0	0						
VIII NORTH DAKOTA	0	0	0	0	0	0	0	0	0	0	0	0						
V OHIO	3	0	0	0	0	2	0	1	0	1	0	2						
VI OKLAHOMA	0	0	0	0	0	0	0	0	0	0	0	0						
X OREGON	0	0	0	0	0	0	0	0	0	0	0	0						
III PENNSYLVANIA	2	0	0	1	0	1	0	0	0	2	0	0						
I RHODE ISLAND	2	0	1	0	0	1	0	0	0	1	1	0						
IV SOUTH CAROLINA	1	0	0	0	1	0	0	0	1	0	0	0						
VIII SOUTH DAKOTA	0	0	0	0	0	0	0	0	0	0	0	0						
IV TENNESSEE	1	0	0	0	0	0	1	0	0	1	0	0						
VI TEXAS	1	0	0	0	0	0	1	0	0	1	0	0						
VIII UTAH	0	0	0	0	0	0	0	0	0	0	0	0						
I VERMONT	2	0	0	0	0	2	0	0	0	0	0	2						
III VIRGINIA	0	0	0	0	0	0	0	0	0	0	0	0						
X WASHINGTON	0	0	0	0	0	0	0	0	0	0	0	0						
III WEST VIRGINIA	0	0	0	0	0	0	0	0	0	0	0	0						
V WISCONSIN	4	0	0	0	2	2	0	0	1	3	0	0						
VIII WYOMING	0	0	0	0	0	0	0	0	0	0	0	0						
TOTAL US	44	6	4	7	7	14	5	1	6	31	3	4	15	7	8	3	12	18

KEY FOR SIZES

A	LESS THAN	20
B	BETWEEN	20 and 50
C	BETWEEN	50 and 100
D	BETWEEN	100 and 250
E	BETWEEN	250 and 500
F	BETWEEN	500 and 1000
G	GREATER THAN	1000

KEY FOR AGES

H	LESS THAN	5
I	BETWEEN	5 and 30
J	BETWEEN	30 and 50
K	GREATER THAN	50

KEY FOR PROCESSES & PRODUCTION

L	CARBON ZINC
M	ALKALINE
N	MERCURY
O	MAGNESIUM
P	SILVER
Q	OTHER

A STATE BY STATE LISTING OF PROCESS TYPES CANNOT BE GIVEN TO AVOID DISCLOSURE OF INDIVIDUAL PLANTS

REGION	TOTAL	PLANT SIZE A	B	C	D	E	F	G	PLANT AGE H	I	J	K	PROCESS TYPE L	M	N	O	P	Q
REGION 1	5	0	2	0	0	3	0	0	0	2	1	2						
REGION 2	6	2	0	1	1	2	0	0	1	4	1	0						
REGION 3	6	1	1	3	0	1	0	0	1	4	1	0						
REGION 4	8	0	0	0	3	2	3	0	1	7	0	0						
REGION 5	12	1	1	1	3	4	1	1	2	8	0	2						
REGION 6	1	0	0	0	0	0	1	0	0	1	0	0						
REGION 7	2	0	0	0	0	2	0	0	0	2	0	0						
REGION 8	2	0	0	2	0	0	0	0	0	2	0	0						
REGION 9	2	2	0	0	0	0	0	0	1	1	0	0						
REGION 10	0	0	0	0	0	0	0	0	0	0	0	0						
TOTAL US	44	6	4	7	7	14	5	1	6	31	3	4	15	7	8	3	12	18

A REGIONAL LISTING OF PROCESS TYPES CANNOT BE GIVEN TO AVOID DISCLOSURE OF INDIVIDUAL PLANTS

TABLE 9.
SIC 3692 DISTRIBUTION OF ANNUAL PRODUCTION OF PRIMARY BATTERIES (METRIC TONS)

REGION/STATE	Total No.	Carbon Zinc 1973	Alkaline-Manganese 1973	Mercury 1973	Magnesium Carbon 1973	Silver Oxide 1973	Other* 1972
IV Alabama	0	0	0	0	0	0	0
X Alaska	0	0	0	0	0	0	0
IX Arizona	0	0	0	0	0	0	0
VI Arkansas	0	0	0	0	0	0	0
IX California	2	0	0	0	0	13.6	0
VIII Colorado	2	0	0	0	0	22.7	113.5
I Connecticut	Combined with Vermont						
III Delaware	0	0	0	0	0	0	0
IV Florida	Combined with South Carolina and Tennessee						
IV Georgia	0	0	0	0	0	0	0
IX Hawaii	0	0	0	0	0	0	0
X Idaho	0	0	0	0	0	0	0
V Illinois	3	2837.5	0	325.5	0	0	61.3
V Indiana	2	0	0	0	0	5.4	0
VII Iowa	Combined with Missouri						
VII Kansas	0	0	0	0	0	0	0
IV Kentucky	0	0	0	0	0	0	0
VI Louisiana	0	0	0	0	0	0	0
I Maine	0	0	0	0	0	0	0
III Maryland	4	0	0	0	0	5.4	10.8
I Massachusetts	0	0	0	0	0	0	0
V Michigan	0	0	0	0	0	0	0
V Minnesota	0	0	0	0	0	0	0
IV Mississippi	0	0	0	0	0	0	0
VII Missouri	2	2996.4	0	0	0	27.2	1589
VIII Montana	0	0	0	0	0	0	0
VII Nebraska	0	0	0	0	0	0	0
IX Nevada	0	0	0	0	0	0	0
I New Hampshire	0	0	0	0	0	0	0
II New Jersey	3	2837.5	0	0	0	0	1634.4
VI New Mexico	0	0	0	0	0	0	0
II New York	3	0	0	548.9	0	30.9	72.6
IV North Carolina	5	30,021	4313	381.4	2781	217.9	68.1
VIII North Dakota	0	0	0	0	0	0	0
V Ohio	3	34,439	0	0	0	0	1543.6
VI Oklahoma	0	0	0	0	0	0	0
X Oregon	0	0	0	0	0	0	0
III Pennsylvania	2	2,270	233.4	0	0	0	0
I Rhode Island	2			0.91		49.9	
IV South Carolina	Combined with Florida and Tennessee						
VIII South Dakota	0	0	0	0	0	0	0
IV Tennessee	3	227	0	18.2	94	0	0
VI Texas	1	0	0	0	817.2	0	0
VIII Utah	0	0	0	0	0	0	0
I Vermont	3	736.4	131.7	59	0	60.8	40
III Virginia	0	0	0	0	0	0	0
X Washington	0	0	0	0	0	0	0
III West Virginia	0	0	0	0	0	0	0
V Wisconsin	4	19,556	7640.4	511.2	0	90.8	0
VIII Wyoming	0	0	0	0	0	0	0
TOTAL	44	95,920.2	14,087.2	1845.1	3692.2	524.8	5133.4
Region I	5	736.4	131.7	59	0	110.8	40.9
II	6	2,837.5	0	548.9	0	30.9	1707
III	6	2,270	233.4	0	0	5.4	10.8
IV	6	30,248	6,081.8	399.5	2874.7	217.9	68.1
V	12	56,832	7,640.4	836.7	0	96.2	1604.9
VI	1	0	0	0	817.2	0	0
VII	2	2,996.3	0	0	0	27.2	1589
VIII	2	0	0	0	0	22.7	113.5
IX	2	0	0	0	0	13.6	0
X	0	0	0	0	0	0	0

*1973 data not available.

5.0 WASTE CHARACTERIZATION

5.1 Introduction

The previous section on industry characterization described the Storage and Primary Batteries Industries in terms of plant sizes and locations, plant ages, types of products, and product production in order to present an overview of the nature of the industry and provide a data base for projection of industry wastes on a national basis.

This section further assesses the industries by describing the production processes involved, the individual wastes which result from each process, the identification of those wastes destined for land disposal which are considered to be potentially hazardous to the environment, and the quantities of waste generated by each segment of the industry. (For discussion of rationale see Section 5.4.3.) Projections for the amounts of potentially hazardous wastes which will be produced in 1977 and 1983 are based upon two considerations:

(a) Changing production patterns and methods within the industry; and

(b) The effects of future air and water regulations on the generation of potentially hazardous wastes destined for land disposal.

The waste characterization will be discussed and analyzed on a product type basis within each SIC code. Wherever it is possible, a typical mass balanced process diagram is given for each of the major battery types which go to make up the 95% level of the merchant production within the SIC code. However, due to proprietary considerations, a mass balancedprocess diagram could not be constructed for many of the specific battery types, and in such cases the potentially hazardous wastes from the process were identified and the amounts of these wastes were quantified on the basis of a unit of product. In all cases, the mass balances or hazardous waste factors are based upon 1000 units of mass of the dry product. For example, the average amount of zinc metal waste from the production of carbon zinc batteries was found to be about 3.812 kg per 1000 kg of carbon-zinc batteries produced. In most instances, the process diagram-mass balance not only concerns itself with the potentially hazardous waste materials from the battery production process, but it also identifies the other materials which comprise the remainder of the battery. Often the quantities of non-hazardous materials as well as the quantities of hazardous materials used to manufacture the battery product are considered by the battery producers to be proprietary, and thus were not divulged to the contractor. Generally, however, some information concerning the magnitude of the amount of hazardous waste destined for land disposal was made available.

The waste factors for potentially hazardous materials were derived for a "typical plant" by using production weighted averages of wastes from a number of plants. For the purposes of this study the determination of a "typical" plant was made on the following basis:

(a) The weighted average of the production output for all plants producing the given battery;

(b) Similar weighted averages for age; and

(c) Geographical location of all plants. For example, if all plants producing a specific battery-type are in Northeastern U.S., this is noted as "typical" for this type of production. If locations are widely scattered around the U.S., then this is noted as "typical" for this type of production. Finally if two plants exist, one on the West Coast and one on the East Coast, this situation is described as "typical" for the particular industry.

The use of "typical plants" rather than actual plants has a number of distinct advantages including maintenance of confidentiality of supplied information and avoidance of using "atypical" facilities. Experience has shown that industry is soon able to identify any plant designated by number or other simple code. This loss of confidentiality (which makes some industry members hesitant to supply information) is largely avoided by the typical plant approach, although it must be pointed out that the defined "typical plant" may not necessarily conform to any existing plant. The description of the "typical plant" for each battery type is discussed in the appropriate waste characterization section.

5.2 Waste Characterization for SIC 3691 Storage Batteries

As noted earlier, the lead-acid storage cell, the nickel-cadmium storage cell, the cadmium-silver storage cell, and the zinc-silver storage cell constitute greater than 95% of the merchant production in the SIC 3691 category.

5.2.1 Lead-Acid Storage Battery

The lead-acid battery is comprised of two electrodes and a sulfuric acid electrolyte. The anode contains lead, leadsulfate and lead monoxide, while the cathodes contain lead dioxide and other lead containing species. The plates (electrodes) of these batteries are made up of two components: the first being an inactive lead grid which provides mechanical support for the active materials and a conductive path for the current, and the second being a lead-oxide-sulfate paste which is applied and bonded to the grids. The plates are then activated as follows:

(a) For the cathodes, the lead-oxide-sulfate is oxidized to PbO_2; and

(b) For the anodes, the lead oxide is reduced to lead.

In addition to lead the grid and electrode materials also contain other elements (such as antimony) which are added to the lead used for the grids. Some tin may also be alloyed with the lead used in the grid construction.

In preparation of the active materials, lead oxide (black lead) is used. The oxide is produced (by other companies) by a modified Barton process so that the resulting product consists of lead oxide with elemental lead dispersed through it. Some of the lead oxide is then used to produce lead sulfate, which is also utilized for battery production. In addition to the lead oxides and sulfates, several other materials (e.g., wood flour, Dynel fibers) are used as binders in electrode preparation. With the electrode materials and the dilute sulfuric acid electrolyte other materials used in lead-acid battery production include:

(a) Separator components, commonly plastics or rubber; and

(b) Container components, commonly vulcanized rubber, polyethylene, nylon, or acrylics.

The polymeric materials are almost always purchased and are only formed to give desired product shapes. The major production operations involved in lead-acid storage battery manufacture are shown in Figure 8. This figure shows a mass-balanced flow diagram of a "typical" plant based upon 1000 mass units of dry product. Two electrode activation procedures are shown on the diagram; the dry charge line and the wet charge line. Many plants will use either one or the other of these procedures and some plants will use both procedures. For the "typical" plant, the process diagram shows 80% of the production going through the dry charge line and 20% through the wet charge line.

In the dry charge battery line, the electrode element stacks are placed in containers filled with acid and electrical connections are made for the forming process. This charging operation converts the paste to sponge lead in the negative plate and to lead peroxide in the positive plate. During the process, the sulfuric acid becomes slightly more concentrated, and the time required varies from 4 to 20 hours. After the element has been formed, it is removed from the container, permitted to drain for a very short period, rinsed in fresh water, and placed in an oven (or other apparatus) to dry. The dried elements are assembled to a battery case, and the battery posts are then welded in place and the cover sealed to the case. The completed battery is then sent on to washing, painting, and shipping.

In the wet charge battery line, the elements are first placed in a battery case, welded together, posts connected to them, and the battery filled with acid. These batteries then undergo the same forming process as the dry batteries. After forming, the acid is dumped (and, generally, recovered), fresh acid added, and the battery boost charged. Fresh acid is added to the dumped dilute acid, and the mixture is used in batteries entering the forming process. The battery is then washed, painted, and shipped.

The amount of lead solid wastes produced from treatment of wastewater streams is difficult to assess at the present time due to the lack of EPA guidelines or pretreatment standards for wastewater from a lead acid plant. In the absence of guidelines for this industry, a modeled treatment system was developed based upon current industrial practices and the results of this modeled treatment yield quantities of lead in the treated effluent and the amount of lead removed which can be assumed to be the maximum amount destined for land disposal. The treatment system is described in Section 6.2 and this description of the modeled wastewater treatment technology was sent to several companies for their comments and has been subsequently revised to reflect the modifications suggested.

As shown on the process diagram, the wastes from lead-acid battery production include the following:

(a) Wastes produced from the manufacture of grid materials--these will include dusts, dross,and rejects of the raw materials and alloys used. This waste amounts to 30 kg per 1000 kg of product and is comprised of lead and lead alloys.

(b) Wastes produced from the cathode and anode paste preparations. This waste amounts to about 2 kg per 1000 kg of product as lead and lead oxide paste.

(c) Wastes produced from clean-up of the pasting area. This amounts to 5 kg per 1000 kg of product in the form of lead oxide and lead powders suspended in a water effluent of about 750 kg of water.

(d) Wastes produced from reject plates in the curing cycle. These wastes generally consist of 10 kg of lead monoxide and 20 kg of lead per 1000 kg of product.

(e) Wastes produced from reject assembled elements. These rejects consist of 10 kg of lead monoxide and 20 kg of lead per 1000 kg of product.

(f) Wastewater solutions. There are water-borne raw wastes comprised of sulfuric acid (typically 2 to 4%) in water containing suspended and dissolved lead. The sources of lead containing wastewater include the pasting area, the dry

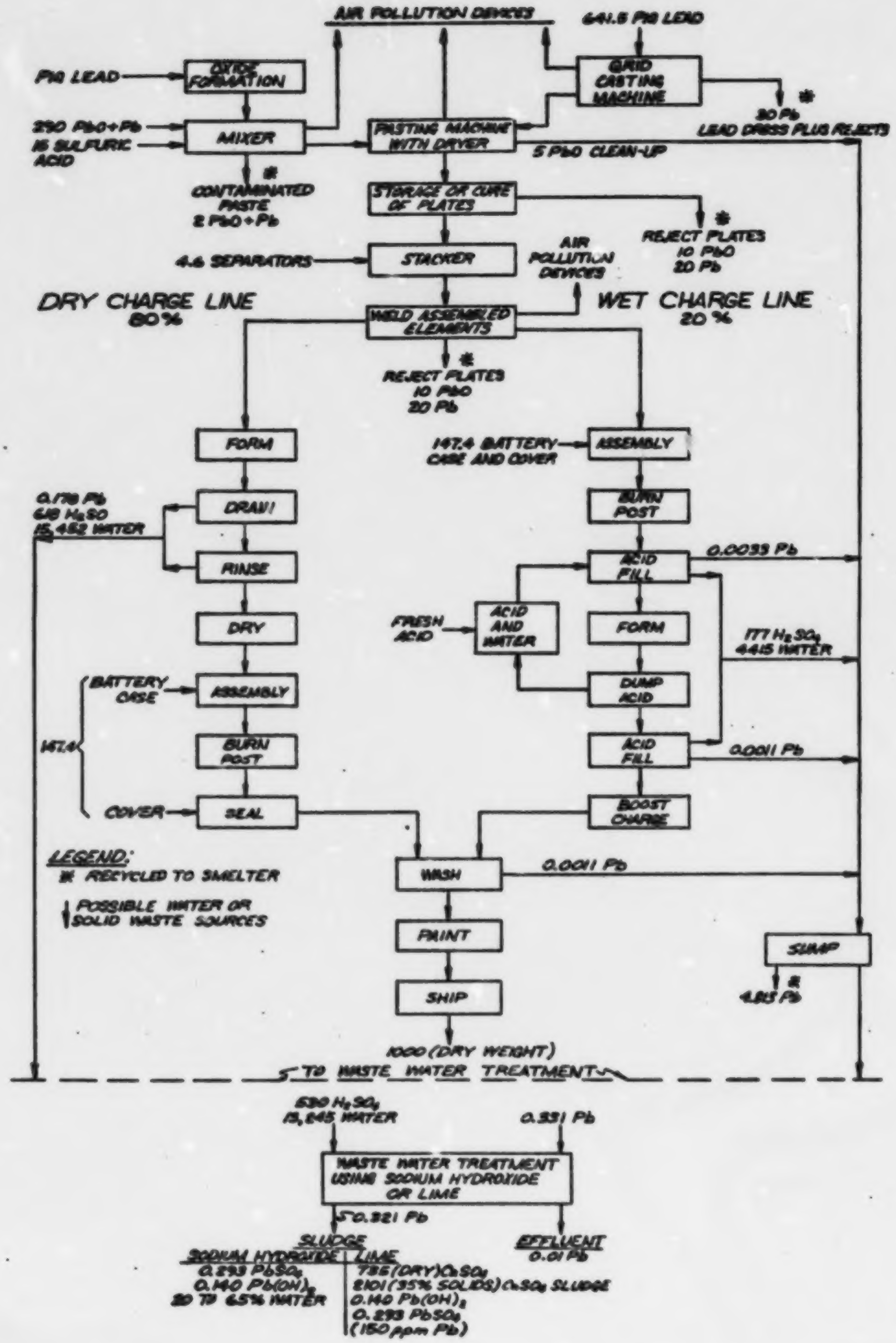
AIR POLLUTION DEVICES
641.5 PIG LEAD
PIG LEAD
OXIDE FORMATION
GRID CASTING MACHINE
290 PbO+Pb
15 SULFURIC ACID
MIXER
PASTING MACHINE WITH DRYER
30 Pb
LEAD DROSS PLUS REJECTS
5 PbO CLEAN-UP
CONTAMINATED PASTE
2 PbO+Pb
STORAGE OR CURE OF PLATES
REJECT PLATES
10 PbO
20 Pb
4.6 SEPARATORS
STACKER
AIR POLLUTION DEVICES
DRY CHARGE LINE
80%
WELD ASSEMBLED ELEMENTS
WET CHARGE LINE
20 %
REJECT PLATES
10 PbO
20 Pb
FORM
147.4 BATTERY CASE AND COVER
ASSEMBLY
0.178 Pb
618 H_2SO
15,452 WATER
DRAIN
BURN POST
RINSE
0.0033 Pb
ACID FILL
FRESH ACID
ACID AND WATER
DRY
FORM
177 H_2SO_4
4415 WATER
BATTERY CASE
ASSEMBLY
DUMP ACID
147.4
BURN POST
ACID FILL
0.0011 Pb
COVER
SEAL
BOOST CHARGE
LEGEND:
* RECYCLED TO SMELTER
POSSIBLE WATER OR SOLID WASTE SOURCES
WASH
0.0011 Pb
PAINT
SUMP
4.815 Pb
SHIP
1000 (DRY WEIGHT)
TO WASTE WATER TREATMENT
530 H_2SO_4
15,845 WATER
0.331 Pb
WASTE WATER TREATMENT USING SODIUM HYDROXIDE OR LIME
0.321 Pb
SLUDGE
SODIUM HYDROXIDE
0.293 $PbSO_4$
0.140 $Pb(OH)_2$
20 TO 65% WATER
LIME
735 (DRY) $CaSO_4$
2101 (35% SOLIDS) $CaSO_4$ SLUDGE
0.140 $Pb(OH)_2$
0.293 $PbSO_4$
(150 ppm Pb)
EFFLUENT
0.01 Pb

Figure 8. Major Production Operations in Lead-Acid Storage Battery Manufacture

and wet charge forming areas, and the assembled battery washing area. Also in cases where a battery breaker is located on site with the battery plant, there will be an additional wastewater stream. A typical plant producing 20% wet charge and 80% dry charge batteries would have a lead raw waste factor of 0.331 kg of lead (suspended and dissolved) per 1000 kg of batteries.

(g) Sludges recovered from treatment of wastewater streams. These wastes consist of lead hydroxide and lead sulfate at 0.541 kg per 1000 kg of product (80% solids basis) for those plants using sodium hydroxide neutralization. The composition of the sludge typically will include lead sulfate (0.293 kg per 1000 kg), lead hydroxide (0.140 kg per 1000 kg) with a water content ranging from 20 to 65%. For those plants using lime neutralization, a calcium sulfate sludge is produced of 735 kg (dry basis) per 1000 kg of product. The composition of the sludge typically will include calcium sulfate (2101 kg per 1000 kg at 35% solids basis), lead hydroxide (0.140 kg per 1000 kg), lead sulfate (0.293 kg per 1000 kg) with a lead content of approximately 150 mg per liter.

Information received from a number of large and small manufacturers of lead-acid batteries indicates that all the scrap wastes from the process (e.g. grids, paste mix, reject plates, etc.) are recovered and sent to a lead smelter for processing as secondary lead and reuse. This recovery and recycle will not be covered herein, since it is not considered a treatment or disposal technology, but part of the basic process. Hence, with regard to the raw wastes mentioned above, all of the solids, dusts and pastes from (a), (b), (d), (e) and some of suspended lead in (c), (f), and (g) are recovered and recycled to a lead smelter as a course of normal operation.

The "typical" lead-acid battery plant described herein employs 100 to 250 people, is 20 years old and produces 8,233,300 kg of batteries annually. A typical location is within a large population center (usually a metropolitan area) with access to municipal water and sewage systems.

The potentially hazardous wastes resulting from a typical lead-acid battery manufacturing process generally result from the wastewater effluent treatment systems. The sludge from the treatment systems typically contains lead sulfate, lead hydroxide and a small amount of suspended lead. These materials constitute a potentially severe environmental hazard due to their relative solubilities and toxicity as described in Appendix A.

Table 10 summarizes the wastes resulting from a "typical" lead-acid battery manufacturing process. The assumptions used to construct the typical plant are:

(a) 1000 kg of batteries (dry weight) as the production basis;

Table 10. Lead-Acid Typical Plant

A. Annual Production = 8,233,300 kg (dry basis) of batteries
Dry Charge Type = 6,586,630 kg
Wet Charge Type = 1,646,670 kg

B. Waste Characterization

1. Wastewater Treatment Sludge Using Caustic Soda Neutralization

Pb raw waste factor = 0.331 kg per 1000 kg batteries
Pb effluent factor = 0.01 kg per 1000 kg batteries
Pb sludge factor = 0.324 kg per 1000 kg batteries
Composition of sludge
  $PbSO_4$ = 0.293 kg per 1000 kg batteries
  $Pb(OH)_2$ = 0.140 kg per 1000 kg batteries
  Water = 20 to 65%
80% solids total sludge = 0.541 kg per 1000 kg batteries
= 4456 kg per year

OR

2. Wastewater Treatment Sludge Using Lime Neutralization*

$CaSO_4$ factor = 735 kg (dry basis) per 1000 kg batteries
= 2101 kg sludge basis (35% solids) per 1000 kg batteries
= 17,298,163 kg per year
= 17,298 metric tons per year

Sludge Characterization

  $CaSO_4$ = 2101 kg per 1000 kg batteries
  $Pb(OH)_2$ = 0.140 kg per 1000 kg batteries
  $PbSO_4$ = 0.293 kg per 1000 kg batteries
  Pb = 150 mg per liter

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*Approximately 20% of the plants in the U.S. use this treatment.

(b) 14.88 kg of lead contained in a typical battery;

(c) 70 gallons (265 liters) of water used to produce one dry charge battery;

(d) 20 gallons (75.5 liters) of water used to produce one wet charge battery; and

(e) that the plant process wastewater stream contains 4% sulfuric acid and 50 mg per liter of lead.

The information used to derive the typical plant was supplied by 12 lead-acid plants located throughout the U.S. and has been reviewed by four corporations which, together, produce over 60% of the lead-acid batteries in the U.S.

Historically, lead-acid manufacturing plants have been relatively small which allowed the plants to be located close to their markets and thus decreased transportation costs. However, the current trend in the industry is to consolidate, so that a smaller number of larger plants can produce virtually the same number of batteries as before. This trend achieves two goals:

(a) Faster and more efficient machinery can be used in each plant, and

(b) The increased efficiency and higher capacity allows a greater control over hazardous wastes.

The lead-acid battery industry is expected to grow at their normal growth rate of 4 or 5% over the next ten years.

5.2.2 Nickel-Cadmium Storage Battery

There are two distinct types of nickel-cadmium cells -- the pocket plate (Jungnertype) cell and the sintered-plate cell. Industry sources have indicated that only a limited number of pocket plate type batteries are now being produced in the U.S.

The positive and negative plates of the pocket plate cell are usually similar in construction, consisting of perforated pockets which contain the active materials. The pockets for both positive and negative plates are made from nickel-plated perforated steel ribbon. Pockets of the negative plates are filled initially with cadmium oxide or cadmium hydroxide, either of which is reduced to metallic cadmium on charging. Some manufacturers of these cells add iron (5 to 30%) to the cadmium in order to obtain the required degree of fineness of the cadmium. The pockets of the positive plate are filled with nickel powder.

Industry sources indicate that the production of pocket-plate type batteries does not generate any water-borne hazardous waste. This is because the active chemicals used are solids and not solutions or pastes. When good housekeeping methods are used within the plant, cells rejected in quality control operations are the only waste generated, and these cells are relcaimed through sale to scrap processors.

The manufacture of sintered-plate batteries, however, does generate some potentially hazardous waste. This type of cadmium battery differs materially in construction and performance from the pocket-plate battery described above. In particular, it contains a cadmium anode, a potassium hydroxide electrolyte and a nickel oxide cathode. For the electrodes, sintered placques containing the active materials are used, and in one process, the placques are made by impregnating binder materials with nickel and cadmium nitrate salts. The nickel and cadmium nitrates are converted to hydroxides in potassium hydroxide solution, and the plates are then washed thoroughly and dried in a hot oven. The impregnation cycle is repeated to deposit the desired amount of active material. The plates then go through a formation treatment which removes impurities and brings the active materials to a condition similar to that existing in working electrodes. The cell is then assembled into final form using an absorbent plastic separator and a nickel-plated steel case. With the addition of the alkaline electrolyte, the batteries are ready for electrical testing, packing,and shipping.

There are currently three distinct manufacturing processes used for preparing the electrodes of the sintered plate batteries, and the preceding paragraph described the worst case (from an environmental standpoint) of the three, due to the high concentration of cadmium and nickel compounds contained in the wash water. The other processes in use are:

(a) An electrolytic deposition process which deposits active materials directly on the sintered plates. This process does produce wastewater containing nickel and cadmium compounds, though the amounts are not as great as in the impregnation process described above; and

(b) A pressed-powder process involving active materials mixed with binders in a dry powder form. The powder mix is pressed onto a wire mesh or expanded metal grid in a mold. This is a dry process and no wastewater is involved.

A mass-balanced process flow diagram for the impregnation-sintered plate process is shown in Figure 9, and the potentially hazardous wastes from the production of this type of battery include the following:

(a) Wastewaters containing cadmium and nickel salts together with potassium hydroxide. The source of this waste is the washing steps, and the magnitude

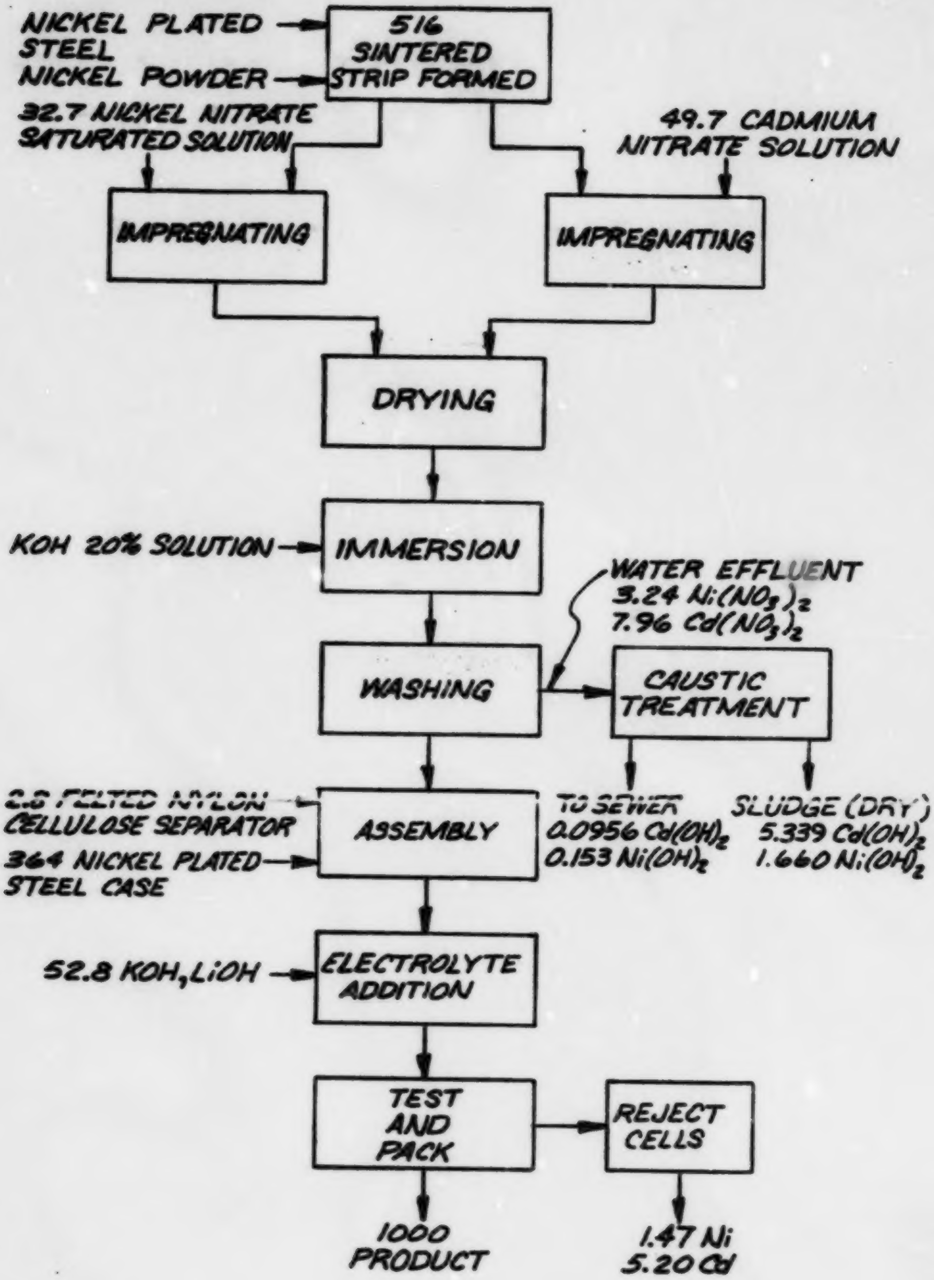

NICKEL PLATED STEEL
NICKEL POWDER
516 SINTERED STRIP FORMED
32.7 NICKEL NITRATE SATURATED SOLUTION
49.7 CADMIUM NITRATE SOLUTION
IMPREGNATING
IMPREGNATING
DRYING
KOH 20% SOLUTION
IMMERSION
WATER EFFLUENT
3.24 $Ni(NO_3)_2$
7.96 $Cd(NO_3)_2$
WASHING
CAUSTIC TREATMENT
2.8 FELTED NYLON CELLULOSE SEPARATOR
364 NICKEL PLATED STEEL CASE
ASSEMBLY
TO SEWER
0.0956 $Cd(OH)_2$
0.153 $Ni(OH)_2$
SLUDGE (DRY)
5.339 $Cd(OH)_2$
1.660 $Ni(OH)_2$
52.8 KOH, LiOH
ELECTROLYTE ADDITION
TEST AND PACK
REJECT CELLS
1000 PRODUCT
1.47 Ni
5.20 Cd

Figure 9. Simplified Diagram of Major Operations in Nickel-Cadmium Sintered-Plate Storage Battery Manufacture

of the waste is estimated to amount to 3.24 kg nickel nitrate and 7.96 kg cadmium nitrate per 1000 kg of product in the untreated wastewater;

(b) Solid wastes recovered from treatment of wastewaters. These are estimated to contain cadmium hydroxide (5.339 kg) and nickel hydroxide (1.660 kg) per 1000 kg of product; and

(c) Rejected batteries from the test and package step. They contain 1.47 kg nickel and 5.20 kg cadmium per 1000 kg of product.

Waste materials comprised of cadmium and nickel and their compounds must be considered hazardous when destined for land disposal because of their potential solubilities and their hazardous effect upon the environment as described in Appendix A.

Table 11 summarizes the wastes generated by the typical nickel cadmium battery plant. These data reflect information supplied by three plants which account for 42% of the U.S. production of that battery type. The waste factors for nickel and cadmium in the rejected cells were calculated from plant supplied data, while the waste factors for cadmium hydroxide and nickel hydroxide in the wastewater treatment sludge were estimated by the contractor on the basis of the amount of cadmium in the treated effluents from two plants and the reported efficiencies of the impregnation process.

The typical nickel cadmium plant has a geographical location in the eastern half of the United States within a populated metropolitan area where municipal water and sewage facilities are available. The age of the plant is 10 to 15 years.

Industry sources have indicated that the two waste streams shown in Table 11 are not in most cases destined for land disposal. In none of the plants surveyed were both of these waste streams going to land disposal. In fact, of the nine plants currently producing nickel cadmium batteries, three plants have no effluent due to their dry production processes, two plants are using on-site impoundment areas (settling ponds) and the remaining plants are selling the sludges to scrap reclaimers. Only two plants were found to use land disposal of scrap batteries, all others selling the scrap to reprocessors.

5.2.3 Cadmium-Silver Oxide Storage Cell

Cadmium-silver oxide cells are manufactured in a process similar to the nickel cadmium cell. Fabrication of the silver electrode begins by impregnating a sintered nickel strip with a silver salt solution. The strip is then dried in a hot oven and immersed in a solution of potassium hydroxide to deposit silver hydroxide in the pores

Table 11. Nickel–Cadmium Typical Plant

A. Annual Production = 446,700 kg of batteries

B. Waste Characterization

1. Nickel
   = 1.47 kg per 1000 kg of batteries from scrap cells
   = 656.6 kg per year

2. Cadmium
   = 5.20 kg per 1000 kg of batteries from scrap cells
   = 2,323 kg per year

3. Cadmium Hydroxide
   = 5.34 kg per 1000 kg of batteries
   = 2,385.4 kg per year (dry basis) from wastewater treatment sludge
   = 6,815.4 kg per year (35% solids basis)

4. Nickel Hydroxide
   = 1.66 kg per 1000 kg of batteries
   = 741.5 kg per year (dry basis) from wastewater treatment sludge
   = 2,118.6 kg per year (35% solids basis)

C. Waste Stream

1. Scrap batteries = 5,360 kg per year

2. Wastewater treatment sludge = 8,934 kg per year

of the electrode. The strip is then thoroughly washed with de-ionized water and allowed to dry. The cadmium electrode is constructed by impregnating a sintered nickel strip with a cadmium salt solution and is dried, immersed and washed as before.

Silver leads are welded to the electrodes and the cell is assembled into final form by wrapping the plates with a two component separator, securing the silver leads to the terminals, and inserting the assembly in a plastic container. Generally, a 30-40% solution of potassium hydroxide is utilized for the electrolyte. The completed cell undergoes quality control testing before it is packed and shipped. The washing operation produces wastewater containing silver and cadmium salts in an alkaline effluent. Other wastes come from quality control rejected whole batteries. A production flow diagram for this cell is shown in Figure 10.

The wastes involved in the production of this type of battery include the following:

(a) Wastewaters containing cadmium and silver salts together with potassium hydroxide. The source of this waste is the washing of the plates, and the waste amounts to 3.01 kg of silver nitrate and 7.96 kg of cadmium nitrate per 1000 kg of batteries produced (dry basis);

(b) Sludge wastes recovered from treatment of the wastewaters. These sludges typically contain 5.34 kg of cadmium hydroxide and 2.24 kg of silver oxide (dry basis) per 1000 kg of batteries produced; and

(c) Rejected batteries from quality control testing. These contain approximately 2.70 kg silver per 1000 kg batteries and 5.20 kg cadmium per 1000 kg batteries.

The silver and cadmium compounds resulting from the manufacture of cadmium-silver oxide storage cells are to be considered potentially hazardous materials if destined for land disposal. The degree of hazard of these materials is discussed in Appendix A.

The typical plant for the manufacture of cadmium-silver oxide storage cells produces 36,240 kg of cells per year. The silver waste factor contained in scrap cells is 2.70 kg per 1000 kg of batteries produced. The cadmium waste factor contained in scrap cells is 5.20 kg per 1000 kg of batteries produced. The washing step of the electrodes is estimated to produce 3.01 kg of silver nitrate and 7.96 kg of cadmium nitrate per 1000 kg of product as a raw waste from the process. After caustic treatment of the wastewater from the washing step is completed, a sludge containing 2.24 kg of silver oxide and 5.34 kg of cadmium hydroxide per 1000 kg

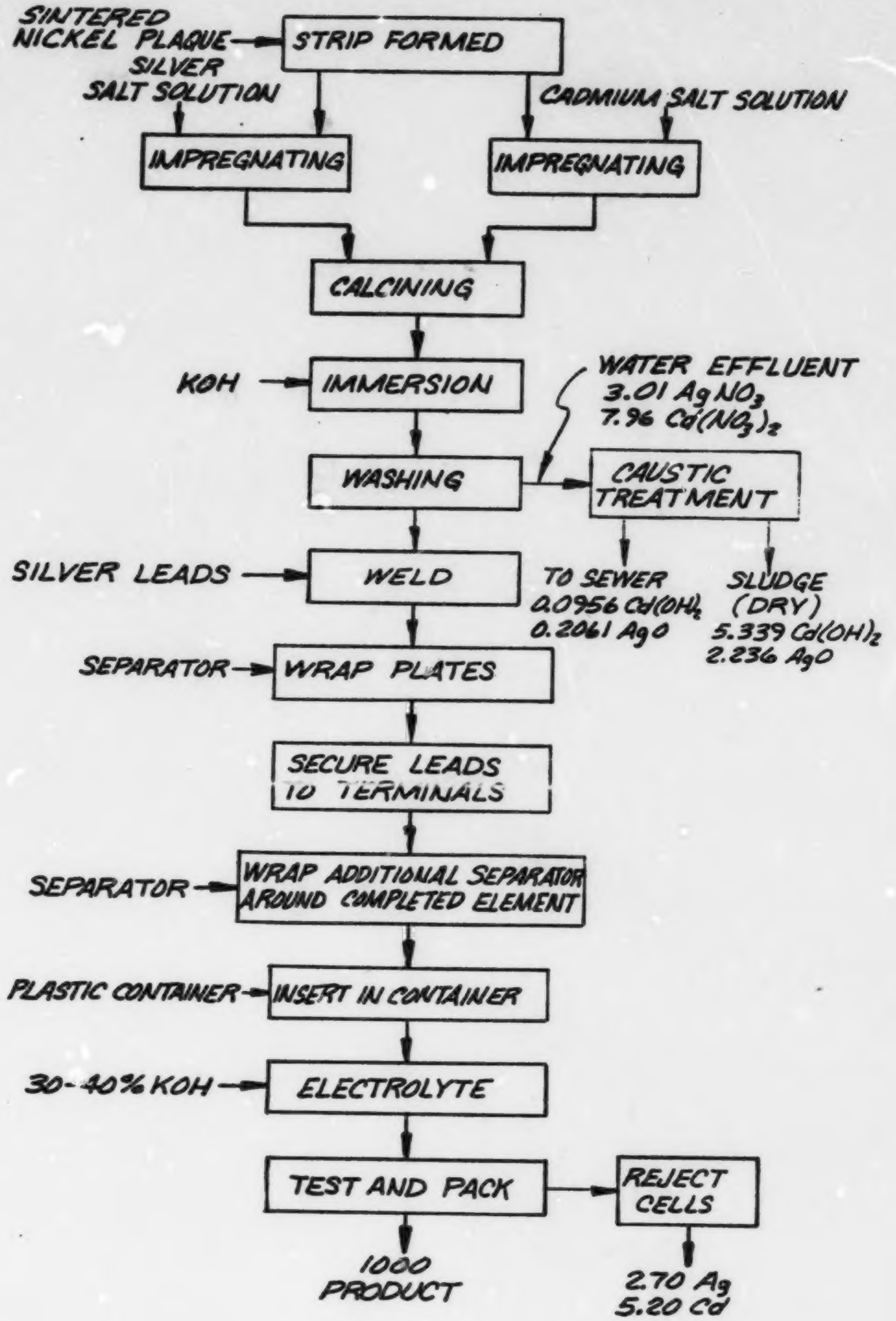

SINTERED NICKEL PLAQUE
STRIP FORMED
SILVER SALT SOLUTION
CADMIUM SALT SOLUTION
IMPREGNATING
IMPREGNATING
CALCINING
KOH
IMMERSION
WATER EFFLUENT
3.01 $AgNO_3$
7.96 $Cd(NO_3)_2$
WASHING
CAUSTIC TREATMENT
SILVER LEADS
WELD
TO SEWER
0.0956 $Cd(OH)_2$
0.2061 AgO
SLUDGE (DRY)
5.339 $Cd(OH)_2$
2.236 AgO
SEPARATOR
WRAP PLATES
SECURE LEADS TO TERMINALS
SEPARATOR
WRAP ADDITIONAL SEPARATOR AROUND COMPLETED ELEMENT
PLASTIC CONTAINER
INSERT IN CONTAINER
30-40% KOH
ELECTROLYTE
TEST AND PACK
REJECT CELLS
1000 PRODUCT
2.70 Ag
5.20 Cd

Figure 10. Simplified Diagram of Major Operations in Cadmium-Silver Secondary Cell Production

of product remains. The waste stream is made up of 435 kg of batteries per year as scrap cells in addition to the sludge previously mentioned from wastewater treatment as summarized in Table 12.

These plants are found on both the east and west coastal regions and are typically located within a municipality where a water source and sewer facilities are available. The typical plant age is estimated to be 10 years. The production figures were based upon three plants. The amount of rejected cells in the waste stream was computed by assuming a 1.2% rejection rate from the process.

The characterization of the wastes for the typical plant were estimated to be the same as for nickel cadmium with adjustments made for differences in formula weights for different compounds. For example, the waste factor for nickel in rejected nickel cadmium cells (1.47 kg per 1000 kg batteries) was adjusted for the higher formula weight for silver to arrive at the 2.70 kg per 1000 kg batteries for rejected silver in cadmium-silver oxide cells.

The actual amounts of hazardous waste destined for land disposal from the production of this cell could not be determined from industry sources, but the reclamation of valuable materials such as silver and cadmium would be an economic necessity for the manufacturers of this battery type. On the basis of economic considerations and information from industry sources, there are no potentially hazardous wastes destined for land disposal from this process.

5.2.4 Zinc-Silver Oxide Secondary Cell

The details of the fabrication of the zinc-silver oxide battery are rather limited in the unclassified literature, and production techniques vary according to the manufacturer. The most generally used process involves the use of dry powder press techniques for the zinc electrode and a sintered powder technique for the silver electrode. The fabrication of the silver electrode consists of sintering silver powder onto an expanded metal grid. The zinc electrode is constructed by pressing a powdered zinc oxide mix onto a zinc mesh screen in a mold. The mix contains zinc oxide powder, 4 to 10% mercuric oxide, and organic binding agents. The electrode undergoes a formation treatment in a 5% solution of potassium hydroxide. The plates are then rinsed in water, drained, and air-dried in a circulating air chamber. The electrodes are then assembled with a separator of multiple layers and inserted in a steel or plastic case. An electrolyte of potassium hydroxide (concentration 30 to 45%) is added, and the battery goes through quality control testing before it is packaged. (17) A process flow diagram for construction of the cell is shown in Figure 11.

Table 12. Cadmium-Silver Oxide Typical Plant

A. Annual Production = 36,240 kg of batteries per year

B. Waste Characterization

1. Silver
   = 2.70 kg per 1000 kg batteries
   = 97.8 kg per year

2. Cadmium
   = 5.20 kg per 1000 kg batteries
   = 188.4 kg per year

3. Silver oxide
   = 2.24 kg per 1000 kg batteries as sludge (dry basis)
   = 81.2 kg per year

4. Cadmium Hydroxide
   = 5.34 kg per 1000 kg batteries as sludge (dry basis)
   = 193.5 kg per year

C. Waste Stream = 435 kg of scrap batteries per year

D. Typical geographical location is in a large metropolitan area with water and sewer facilities available.

E. Typical age — 10 years

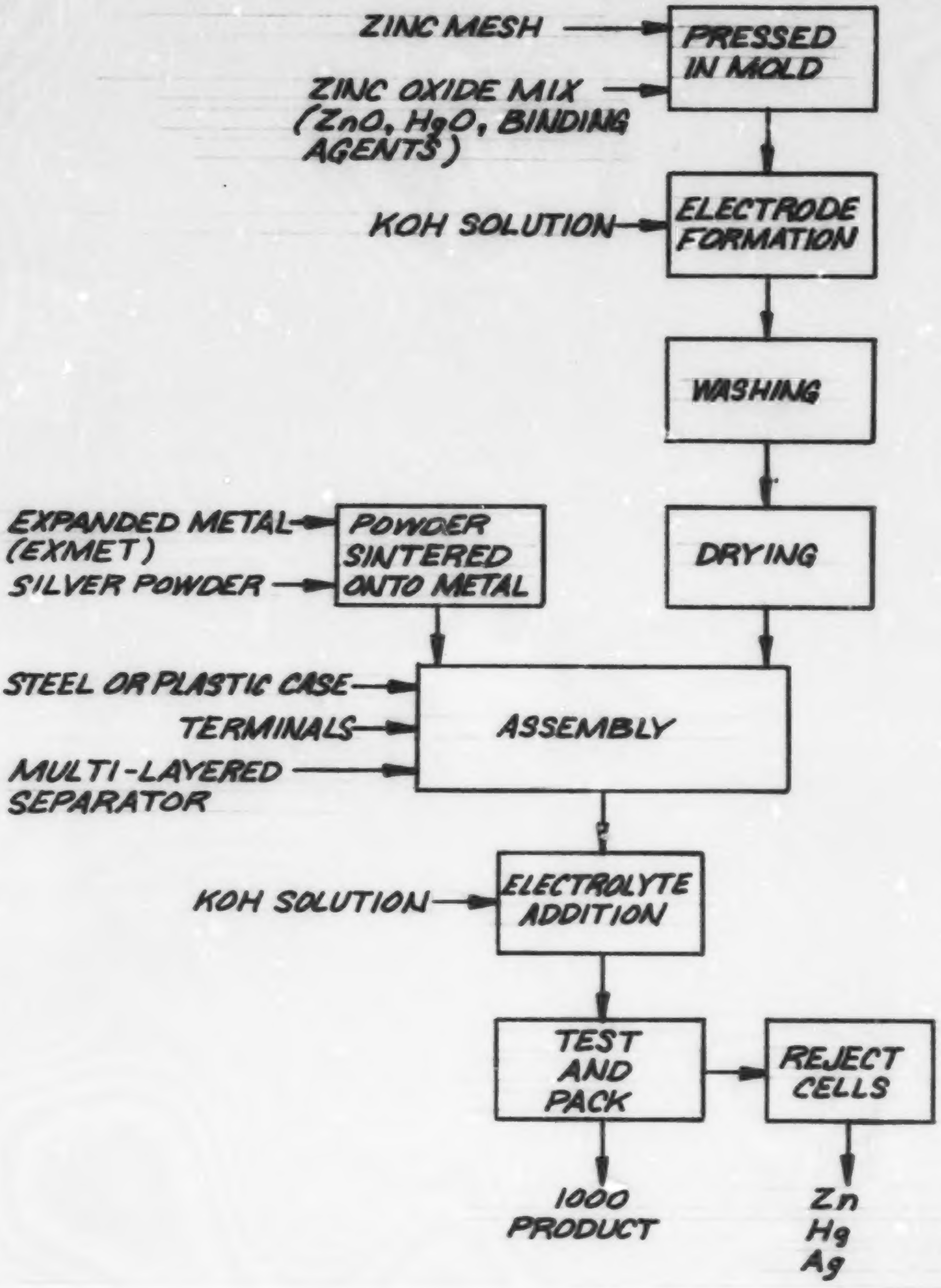

ZINC MESH
PRESSED IN MOLD
ZINC OXIDE MIX (ZnO, HgO, BINDING AGENTS)
KOH SOLUTION
ELECTRODE FORMATION
WASHING
EXPANDED METAL (EXMET)
SILVER POWDER
POWDER SINTERED ONTO METAL
DRYING
STEEL OR PLASTIC CASE
TERMINALS
MULTI-LAYERED SEPARATOR
ASSEMBLY
KOH SOLUTION
ELECTROLYTE ADDITION
TEST AND PACK
REJECT CELLS
1000 PRODUCT
Zn
Hg
Ag

Figure 11. Simplified Diagram of Major Operations in Zinc-Silver Oxide Secondary Battery

The wastes from the production of this cell could not be determined from industry sources, but there appear to be no hazardous water-borne wastes from this process aside from potassium hydroxide. The potentially hazardous waste products from rejected cells would be zinc, mercury, and silver, but since the scrap cells contain silver, they are sold to scrap reclaimers for their silver content.

No typical plant was derived for this battery, due to lack of industry supplied data on its production. On the basis of economic considerations and information from industry sources, there are no potentially hazardous wastes destined for land disposal from this process.

5.2.5 Iron-Nickel Oxide Alkaline Storage Cell (Edison)

This storage cell was produced in large quantities in the U.S. over the past 40 years, but, in recent times, has become only a limited production item. According to industry sources, this battery is not in production at the present time and there are no plans to resume production in the near future.

Earlier the cell was produced in a fashion similar to that of the pocket type nickel cadmium cells. The pockets for both positive and negative plates are made from perforated steel ribbon, and the pockets of the negative plate are filled initially with a mixture of powdered nickel and nickel peroxide, which is reduced to metallic nickel on the first charge. The pockets of the positive plate are filled with iron powder. The positive and negative plate pockets are attached to a frame, connected, and spaced with the necessary hardware, and rubber or plastic insulators are inserted. The assembly is then placed within a nickel plated steel container, a 20% potassium hydroxide — lithium hydroxide solution is added, and the cell is sealed, painted, tested, and packaged. (17)

Again, the wastes from the production of this cell could not be determined from industry sources, but there would appear to be no water-borne wastes from this process. The possible waste products would be powdered iron and nickel and their oxides from electrode preparation, as well as quality control rejected batteries.

A typical plant could not be derived from this cell and there are no projections of waste to land disposal, since this battery type is not being produced at the present time.

5.2.6 Nickel-Zinc Storage Cell

This battery is a specialized and limited production item with no significant non-military production at the present time.

The negative electrode is produced from a mixture of zinc and zinc hydroxide, while the positive electrode is produced from sintered nickel. This battery normally operates as a semi-dry battery in that the electrolyte (composed of potassium hydroxide saturated with zinc oxide) is absorbed into the plates and plastic separators. (17)

The wastes from the production of this cell could not be determined from industry sources, but there would appear to be no water-borne wastes from this process. The possible potentially hazardous waste products would be zinc, zinc hydroxide, zinc oxide, and nickel from electrode production as well as quality control rejected batteries.

No typical plant was derived for this battery, due to its limited production status.

5.2.7 Silver-Lead Storage Cell

This battery is a specialized item designed primarily for military use and is produced only in limited quantities.

The silver-lead cell is produced in a configuration and size similar to a small primary mercury button cell. The cathode is produced as a pellet of silver peroxide powder mixed with graphite and pressed into a conducting container of steel. The anode is also a pressed pellet composed of powdered lead or lead-mercury amalgam. A ceramic disc separator is placed in the container between the anode and cathode, and an absorbent sleeve impregnated with potassium hydroxide is inserted. An outer steel cover completes the assembly. (17)

The wastes from the production of this cell could not be determined from industry sources. The potentially hazardous waste products from scrap cells would be lead, mercury, and silver. However, the use of silver in this cell would preclude the manufacturer from land disposal of these cells. The scrap cells from this process would be sold to a scrap reclaimer.

No typical plant was derived from this battery due to its specialized use and limited production.

5.2.8 Mercury-Cadmium Secondary Cell

This battery is a very specialized item, produced only in limited quantities for military application and primarily in small button sizes.

The cadmium cathode is formed by corrugating a cadmium ribbon and pressing it into a steel case. A ceramic insulator-spacer and an absorbent sleeve is then inserted into the case, and a potassium hydroxide electrolyte is impregnated into the sleeve. The zinc-mercury anode is fabricated by pressing zinc amalgam into a pellet and inserting it into the case. An inner steel case is then inserted into the assembly and a steel outer cover added. The cell is quality control tested and packaged for shipment. (17)

The wastes from the production of this cell could not be determined from industry sources. The potentially hazardous waste products from scrap cells would be cadmium, zinc, and mercury. In general, industry sources indicated that scrap cells containing mercury are sold to scrap reclaimers.

5.3 Waste Characterization for SIC 3692 Primary Batteries

The carbon-zinc cell, the carbon-zinc air cell, the alkaline manganese cell, the mercury Ruben and Weston cells, the magnesium-carbon cell, the zinc-silver cells, and the lead reserve cell constitute more than 95% of the merchant production in the SIC 3692 category.

With one exception, these batteries can be characterized as being produced without the use of process water in the production operation. The largest amount of potentially hazardous wastes comes from rejection of scrap cells in the product quality control operation. Two other processing steps, the electrode blending operations and the forming operations, contribute a comparatively minor amount of waste — which industry sources claim is totally recycled to the process.

In general, disposal of rejected batteries appears to be the primary contributor to potentially hazardous waste destined for land disposal from production of this battery type. This problem is very similar to that of the disposal of consumer-used batteries which normally go to a municipal landfill or incineration system — except that battery producers must dispose of a larger number of batteries in a limited area.

5.3.1 Carbon-Zinc Dry Cell

The Leclanche or carbon-zinc dry cell is the type of primary battery manufactured in the greatest quantity in the United States.

This dry cell consists of a zinc alloy container anode, a paste type electrolyte of zinc and ammonium chlorides, water and various inert materials added to maintain the electrolyte in a semi-solid form, and a depolarizer and cathode consisting of manganese dioxide and carbon.

In addition to the manganese dioxide, ammonium and zinc salts, and zinc metal, several other materials are also incorporated into the batteries:

(1) To minimize corrosion, the zinc used is frequently amalgamated. The quantity of mercury used (approximately 0.014% by weight) is optimized by economics and the physical consideration of zinc embrittlement; and

(2) A wide variety of materials are used as separators to prevent electronic shorting of the electrodes. Generally, these are:

   (a) An unsupported gel electrolyte paste of wheat, flour and cornstarch, or

   (b) A paper board supported paste.

The production of carbon-zinc dry cells begins by shaping or purchasing a container from a zinc alloy sheet. A separator of paper board coated with a paste containing mercuric chloride or a gel is then inserted into the container. The separator is followed by a depolarizer of manganese dioxide and carbon black, and an electrolyte of ammonium chloride and zinc chloride. A carbon rod current collector is inserted into the container and is held by a paperboard support washer. The cell undergoes a quality control inspection before it is sealed with an asphalt compound. Top and bottom covers of tin plated steel are formed and attached to the cell. An outer case of steel or paper is decorated, formed, and attached to the cell, and an electrical testing step takes place before the product is finally packaged for shipment.

The wastes from the production of carbon-zinc batteries consist of mercury, zinc, zinc chloride, manganese dioxide, cadmium, and lead. These wastes are contained in rejected batteries from the test and package step of the process diagram shown in Figure 12. These wastes have been quantified in the form of waste factors based upon 1000 kg of batteries produced. The quantities of other constituents used in the cell are considered to be proprietary and were not given to the contractor. The amount of wastes from rejected batteries include 0.0073 kg mercury, 3.812 kg zinc, 0.248 kg zinc chloride, 6.147 kg manganese dioxide, 0.00027 kg cadmium, and 0.00031 kg lead per 1000 kg of batteries produced. The amounts of cadmium and lead are based on the zinc alloy used in making drawn cans. The alloy used in extruded cans may contain approximately ten times the lead and roughly twice the cadmium of that used in drawn cans, although the use of this type of can is not predominant in the industry.

These waste factors and other "typical plant" data were derived by using weighted averages of production wastes from seven plants accounting for approximately 61% of the total U.S. production of carbon-zinc dry cells.

The waste mercury, zinc, zinc chloride, cadmium, and lead are considered potentially hazardous to varying degrees. The hazards of these wastes are discussed in detail in Appendix A.

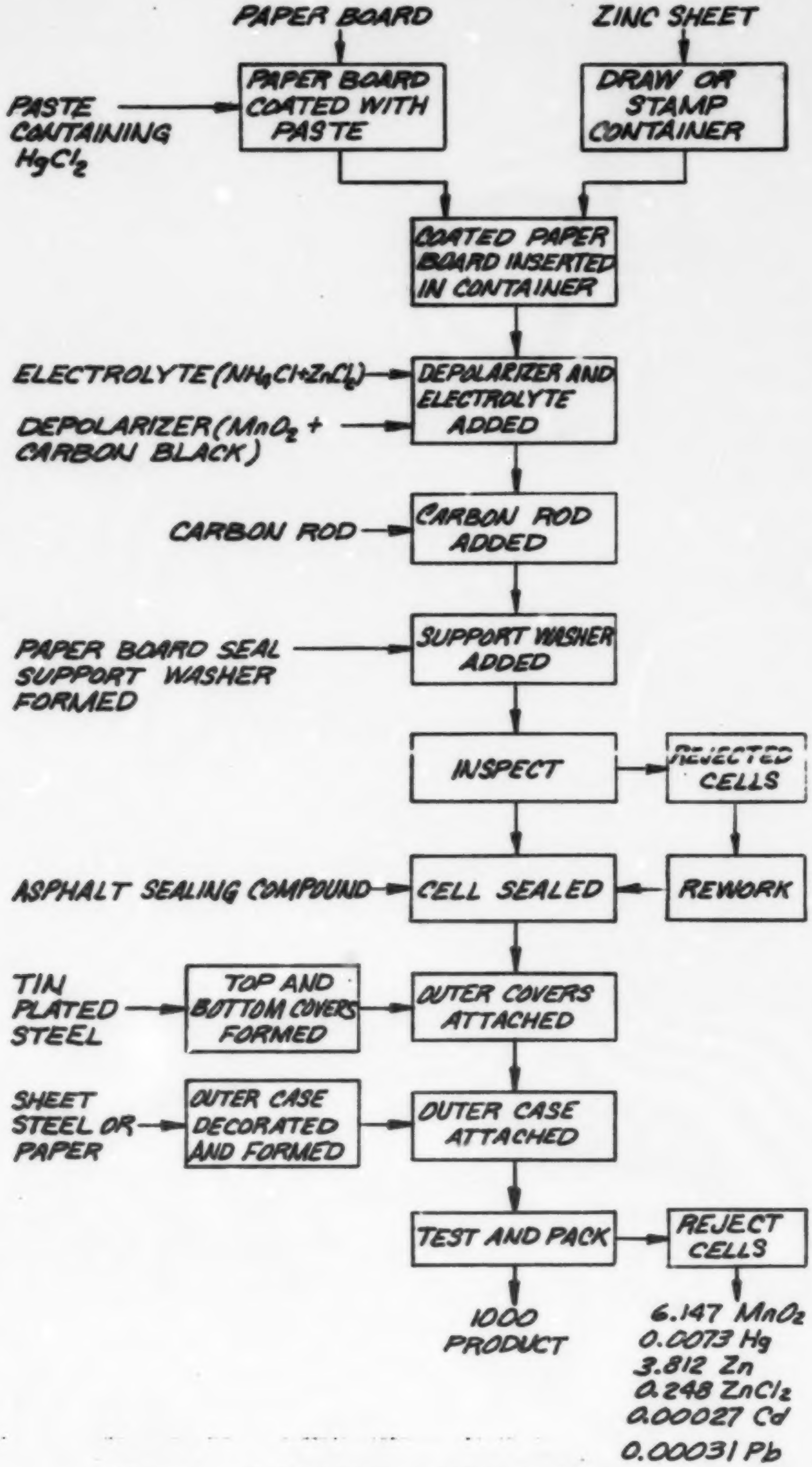

PAPER BOARD
ZINC SHEET
PASTE CONTAINING $HgCl_2$
PAPER BOARD COATED WITH PASTE
DRAW OR STAMP CONTAINER
COATED PAPER BOARD INSERTED IN CONTAINER
ELECTROLYTE ($NH_4Cl + ZnCl_2$)
DEPOLARIZER (MnO_2 + CARBON BLACK)
DEPOLARIZER AND ELECTROLYTE ADDED
CARBON ROD
CARBON ROD ADDED
PAPER BOARD SEAL SUPPORT WASHER FORMED
SUPPORT WASHER ADDED
INSPECT
REJECTED CELLS
ASPHALT SEALING COMPOUND
CELL SEALED
REWORK
TIN PLATED STEEL
TOP AND BOTTOM COVERS FORMED
OUTER COVERS ATTACHED
SHEET STEEL OR PAPER
OUTER CASE DECORATED AND FORMED
OUTER CASE ATTACHED
TEST AND PACK
REJECT CELLS
1000 PRODUCT
6.147 MnO_2
0.0073 Hg
3.812 Zn
0.248 $ZnCl_2$
0.00027 Cd
0.00031 Pb

Figure 12. Simplified Diagram of Major Operations in Carbon-Zinc Battery Manufacture

The typical carbon-zinc dry cell plant has an annual production of 2,270,000 kg of batteries. Wastes from the typical plant stem entirely from rejected completed cells. The wastes consist of mercury in the amount of 0.0073 kg per 1000 kg product, zinc at 3.812 kg per 1000 kg product zinc chloride at 0.248 kg per 1000 kg product, manganese dioxide at 6.147 kg per 1000 kg product, cadmium at 0.00027 kg per 1000 kg product, and lead at 0.00031 kg per 1000 kg product. The waste stream of the typical plant consists of 22,700 kg of batteries.

A typical location of a carbon-zinc dry cell plant is in the Eastern U.S. in a relatively small population center where municipal or private landfills may be used at low cost. The typical age of a dry cell plant is approximately 40 years.

The waste factors (kg of each waste per 1000 kg of battery production) were computed and production weighted from the amounts of wastes supplied by these plants. A rejection rate of 1% was used to arrive at the total waste stream of batteries rejected by the typical plant. The characteristics of the typical plant are summarized in Table 13.

In the past it has not been economically justifiable to recycle rejected carbon-zinc dry cells and batteries. Several factors may reverse this trend or lead to a reduction of plant wastes.

(a) Zinc and manganese dioxide have experienced large increases in price;

(b) Use of a relatively new process in which paper separators replace the old gelatinous type. The paper separators are more easily removed from the cell and thus allow the zinc to be reclaimed more economically;

(c) Better quality control operation; and

(d) Price and scarcity of raw materials.

For these reasons, industry sources feel that a significant reduction in solid waste generated by the carbon-zinc plants will occur in the next 5 to 10 years which implies that a corresponding decrease in the quantity of waste destined for land disposal can be expected.

5.3.2 Carbon-Zinc Air Cell

The manufacturing process of carbon-zinc air cells begins with the formation of a molded plastic container. Lime is placed in the bottom of the container and a porous activated carbon electrode is inserted. Two amalgamated zinc electrodes

Table 13. Carbon-Zinc Typical Plant

A. Annual Production = 2,270,000 kg of batteries

B. Waste Characterization

1. Mercury
   = 0.0073 kg per 1000 kg batteries
   = 16.6 kg per year
2. Zinc
   = 3.812 kg per 1000 kg batteries
   = 8,653 kg per year
3. Zinc Chloride
   = 0.248 kg per 1000 kg batteries
   = 563 kg per year
4. Manganese Dioxide
   = 6.147 kg per 1000 kg batteries
   = 13,950 kg per year
5. Cadmium
   = 0.00027 kg per 1000 kg batteries
   = 0.613 kg per year
6. Lead
   = 0.00031 kg per 1000 kg batteries
   = 0.704 kg per year

C. Waste Stream = 22,700 kg of batteries are formed and placed on either side of the carbon electrode and solid sodium hydroxide is cast around the electrodes. Next a cover and terminals are formed, attached to the case, and the zinc electrode is sealed. (The carbon electrode is left unsealed to allow air to enter and absorb onto the carbon to act as the depolarizer.) Quality control testing takes place before the cells are packed for shipment.

This specialty battery contains a carbon cathode and an amalgamated zinc anode with a solid sodium hydroxide electrolyte. The battery is activated by addition of water to the cell. The zinc anode is amalgamated with mercury. The wastes from this process are in the form of rejected batteries from the test and pack step of the process diagram shown in Figure 13. The wastes contained in the rejected cells are 0.294 kg zinc and 0.00117 kg mercury per 1000 kg of batteries produced.

The waste zinc and mercury from the production of carbon-zinc air cells are considered potentially hazardous when destined for land disposal. The hazardousness of these wastes and related discussions are contained in Appendix A.

The typical carbon-zinc air cell plant has an annual production of 1,540,000 kg of batteries. Wastes from the typical plant stem entirely from rejected complete cells, and consist of zinc in the amount of 0.294 kg per 1000 kg of product or 453 kg per year, and mercury at 0.00117 kg per 1000 kg of product or 1.80 kg per year. The waste stream of the typical plant contains 15,400 kg of scrap cell per year.

The typical location of a carbon-zinc air cell plant is in the eastern U.S. The typical age for a plant of this nature is approximately 40 years. A summary of the typical plants characteristics is given in Table 14.

The typical plant was derived from the response of one producer representing approximately 30% of the air cells produced in the U.S. The waste factors were computed from quantities supplied by the plant, and a rejection rate of 1% was used to arrive at the quantity of cells rejected by the typical plant.

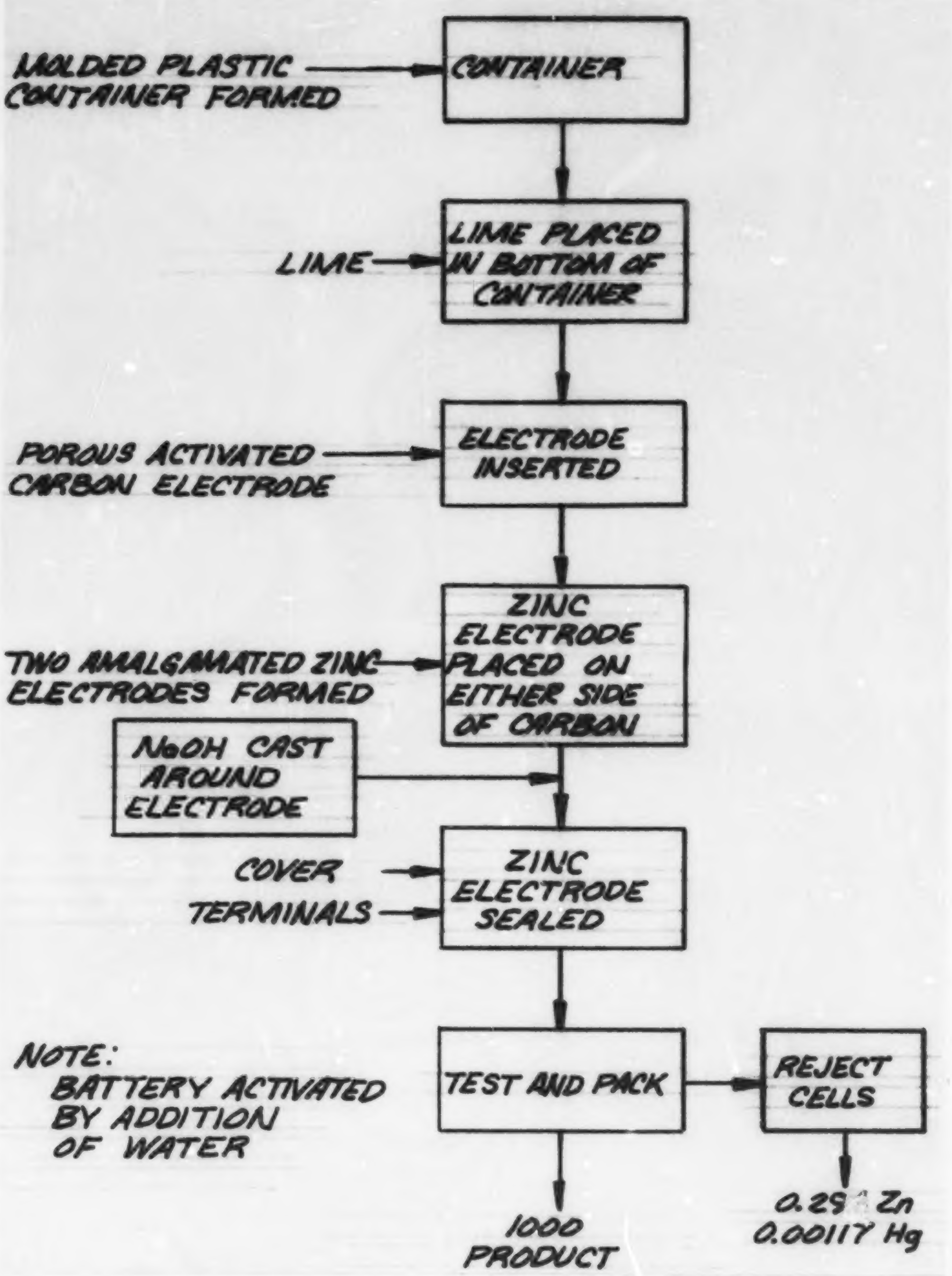

MOLDED PLASTIC CONTAINER FORMED
CONTAINER
LIME
LIME PLACED IN BOTTOM OF CONTAINER
POROUS ACTIVATED CARBON ELECTRODE
ELECTRODE INSERTED
TWO AMALGAMATED ZINC ELECTRODES FORMED
ZINC ELECTRODE PLACED ON EITHER SIDE OF CARBON
NaOH CAST AROUND ELECTRODE
COVER
TERMINALS
ZINC ELECTRODE SEALED
NOTE: BATTERY ACTIVATED BY ADDITION OF WATER
TEST AND PACK
REJECT CELLS
1000 PRODUCT
0.29[illegible] Zn
0.00117 Hg

Figure 13. Simplified Diagram of Major Operations in Carbon-Zinc Air Cell Primary Battery Manufacture

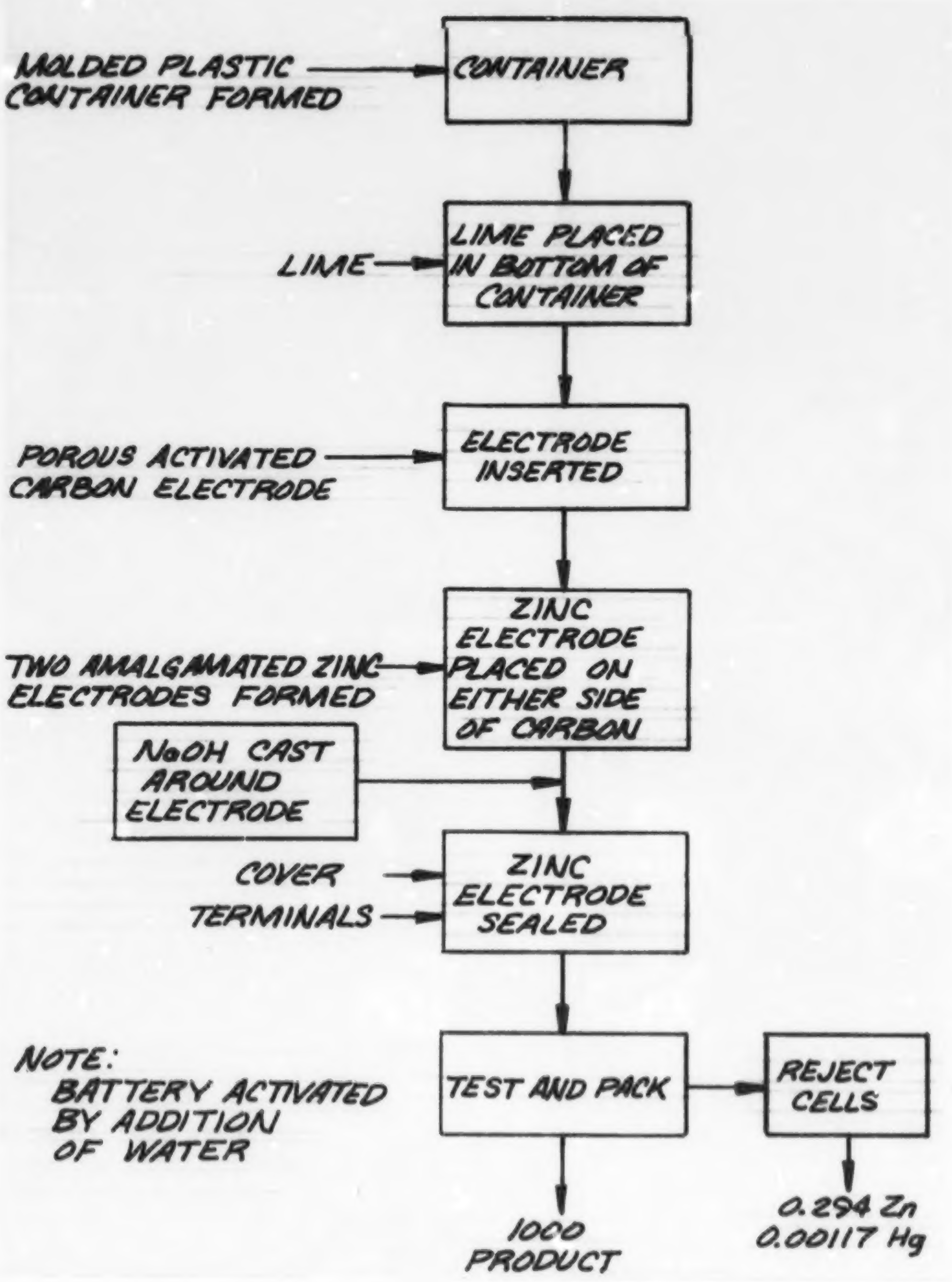

MOLDED PLASTIC CONTAINER FORMED
CONTAINER
LIME
LIME PLACED IN BOTTOM OF CONTAINER
POROUS ACTIVATED CARBON ELECTRODE
ELECTRODE INSERTED
TWO AMALGAMATED ZINC ELECTRODES FORMED
ZINC ELECTRODE PLACED ON EITHER SIDE OF CARBON
NaOH CAST AROUND ELECTRODE
COVER
TERMINALS
ZINC ELECTRODE SEALED
NOTE: BATTERY ACTIVATED BY ADDITION OF WATER
TEST AND PACK
REJECT CELLS
1000 PRODUCT
0.294 Zn
0.00117 Hg

Figure 13. Simplified Diagram of Major Operations in Carbon-Zinc Air Cell Primary Battery Manufacture

Table 14. Air Cell Typical Plant

A. Annual Production = 1,540,000 kg batteries

B. Waste Characterization

  1. Mercury = 0.00117 kg per 1000 kg batteries
     = 1.80 kg per year

  2. Zinc = 0.294 kg per 1000 kg batteries
     = 453 kg per year

C. Waste Stream = 15,400 kg of batteries

D. Typical Location = Eastern U.S.

E. Typical Age = 40 years

F. Number of Employees = 250-500

5.3.3 Alkaline Manganese Dioxide Dry Cell

The manufacturing process for the alkaline dry cell begins with the formation of a container from a nickel plated steel sheet. Carbon and manganese dioxide are pressed together to form a cathode and inserted into the container. Next a separator of polyethylene is formed and inserted. Mercury is then amalgamated with powdered zinc to form the anode and inserted. An electrolyte of potassium hydroxide is then added, and a brass current collector, a nylon seal, and a rivet are formed and inserted into the container. The cells are then inspected in a pre-test step prior to final assembly. Finally, a nickel plated steel pressure spring is added to the cell, nickel plated steel end covers are formed and attached, and a steel jacket is decorated, formed and placed around the cell. A quality control test is performed on the completed cell before it is packaged for shipment.

This variety of battery differs from the carbon-zinc type primarily in the electrolyte used. For the alkaline batteries 30% potassium hydroxide is employed.

In commercial practice, the cathode (which is a mixture of finely divided manganese dioxide and graphite) is held together by either a mechanical packing or the use of organic binders and inert fibers. Polyethylene type materials are used in the separators and zinc powder is used in production of the anodes. In these electrodes, zinc powder is combined with an appropriate gelling agent carboxymethylcellulose, which contains the electrolyte. The zinc anode is amalgamated with mercury (approximately 3 to 6% by weight) to minimize corrosion.

The wastes from this process are in the form of rejected batteries from the test and package step of the process diagram shown in Figure 14. The wastes contained in the rejected batteries are 0.076 kg mercury, 1.622 kg zinc, and 2.744 kg manganese dioxide per 1000 kg of product.

The zinc and mercury wastes associated with the production of the alkaline dry cell must be considered potentially hazardous when destined for land disposal. The mercury wastes are potentially toxic to both the environment and man, while the zinc wastes present a lesser degree of hazard to the environment. The biological and environmental effects of these materials are discussed at length in Appendix A.

The typical alkaline plant produced 2,038,000 kg of batteries per year. Wastes associated with alkaline cell production include mercury at the rate of 0.076 kg per 1000 kg product, or 155 kg per year; zinc at 1.622 kg per 1000 kg product, or 3,306 kg per year; and manganese dioxide at 2.744 kg per 1000 kg product, or 5,592 kg per year. The total waste stream from the typical plant consists of 20,389 kg batteries per year.

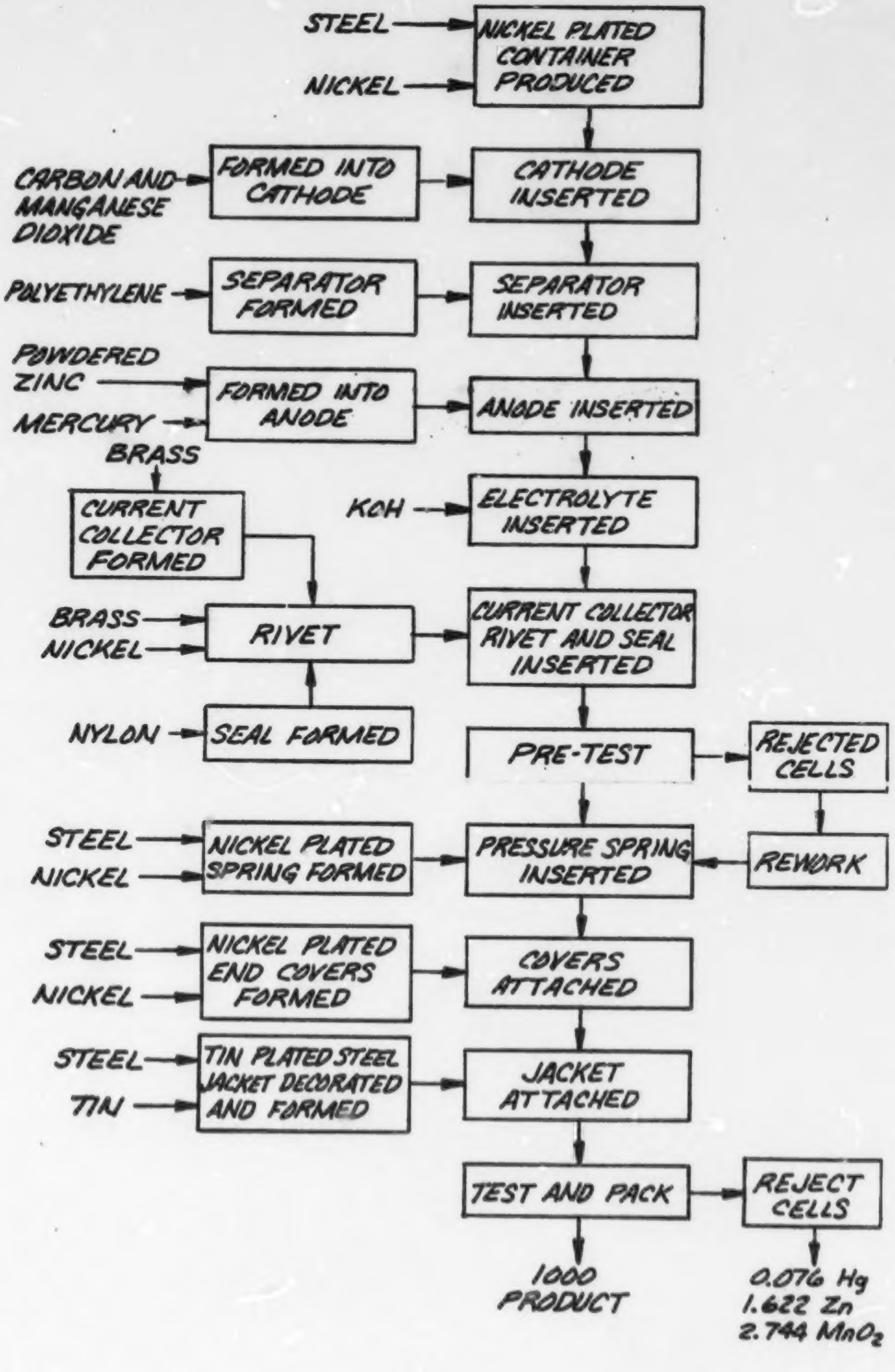

STEEL
NICKEL
NICKEL PLATED CONTAINER PRODUCED
CARBON AND MANGANESE DIOXIDE
FORMED INTO CATHODE
CATHODE INSERTED
POLYETHYLENE
SEPARATOR FORMED
SEPARATOR INSERTED
POWDERED ZINC
MERCURY
FORMED INTO ANODE
ANODE INSERTED
BRASS
CURRENT COLLECTOR FORMED
KOH
ELECTROLYTE INSERTED
BRASS
NICKEL
RIVET
CURRENT COLLECTOR RIVET AND SEAL INSERTED
NYLON
SEAL FORMED
PRE-TEST
REJECTED CELLS
STEEL
NICKEL
NICKEL PLATED SPRING FORMED
PRESSURE SPRING INSERTED
REWORK
STEEL
NICKEL
NICKEL PLATED END COVERS FORMED
COVERS ATTACHED
STEEL
TIN
TIN PLATED STEEL JACKET DECORATED AND FORMED
JACKET ATTACHED
TEST AND PACK
REJECT CELLS
1000 PRODUCT
0.076 Hg
1.622 Zn
2.744 MnO2

Figure 14. Simplified Diagram of Major Operations in Alkaline Dry Battery Manufacture

A typical location of an alkaline plant is in the eastern U.S. in a relatively small population center where municipal or private landfills may be used. The typical age of a plant is approximately 6 years. A summary description of the typical plant is given in Table 15.

The typical plant for alkaline cells was derived from responses by four plants representing 53% of the total U.S. production of this battery type. The waste factors were computed and weighted by production from information supplied by the plants. A rejection rate of 1% was used to arrive at the total waste stream.

5.3.4 Mercury Cell Primary Batteries

This section covers all primary dry batteries of commercial significance which contain large amounts of mercury in the cell. Specifically, there are three of them: the Ruben cell, the Weston cell, and the cadmium-mercury cell.

The manufacturing process of the Ruben cell begins with the fabrication of a nickel plated steel case followed by the formation of a cathode of mercuric oxide and graphite which is pressed into the case. A neoprene disc which serves as the insulator-spacer is formed and added to the base of the cell case. A microporous plastic sleeve is then inserted and impregnated with an alkaline electrolyte.

Next, a zinc amalgam anode is produced and placed in the case. The cell undergoes an electrical testing step before it is sealed with a steel inner top and a nickel plated steel outer top. A final testing step is made before it is packed for shipment.

The Weston cell is constructed by first forming a compartmented vessel from glass. Platinum wire is then sealed into the lower end of each leg of the vessel. In the bottom of one leg is placed mercury and mercurous sulfate, and cadmium amalgam is placed in the bottom of the other leg. The vessel is filled with a cadmium sulfate solution and the open ends of the vessel are sealed. The cell is then tested before it is packed for shipment.

The mercury-cadmium cell is very similar in construction to the Ruben mercury cell with certain proprietary changes in the composition of the electrodes. The positive electrode is manufactured like the mercuric oxide electrode in the button Ruben cells. The negative electrode is made up of cadmium which may be amalgamated with mercury in proportions up to 20% by weight.

The wastes from the Ruben cell process are in the form of rejected batteries from the test and pack step of the process diagram shown in Figure 15. Greater than 95% of the rejected batteries are reclaimed, but some are sent to landfills.

Table 15. Alkaline-Manganese Dioxide Typical Plant

A. Annual Production = 2,038,000 kg batteries

B. Waste Characterization

1. Mercury = 0.076 kg per 1000 kg batteries
   = 155 kg per year

2. Zinc = 1.622 kg per 1000 kg batteries
   = 3306 kg per year

3. Manganese Dioxide = 2.744 kg per 1000 kg batteries
   = 5,592 kg per year

C. Waste Stream = 20,389 kg batteries

D. Typical Location = Eastern U.S.

E. Typical Age = 6 years

F. Number of Employees = 250-500

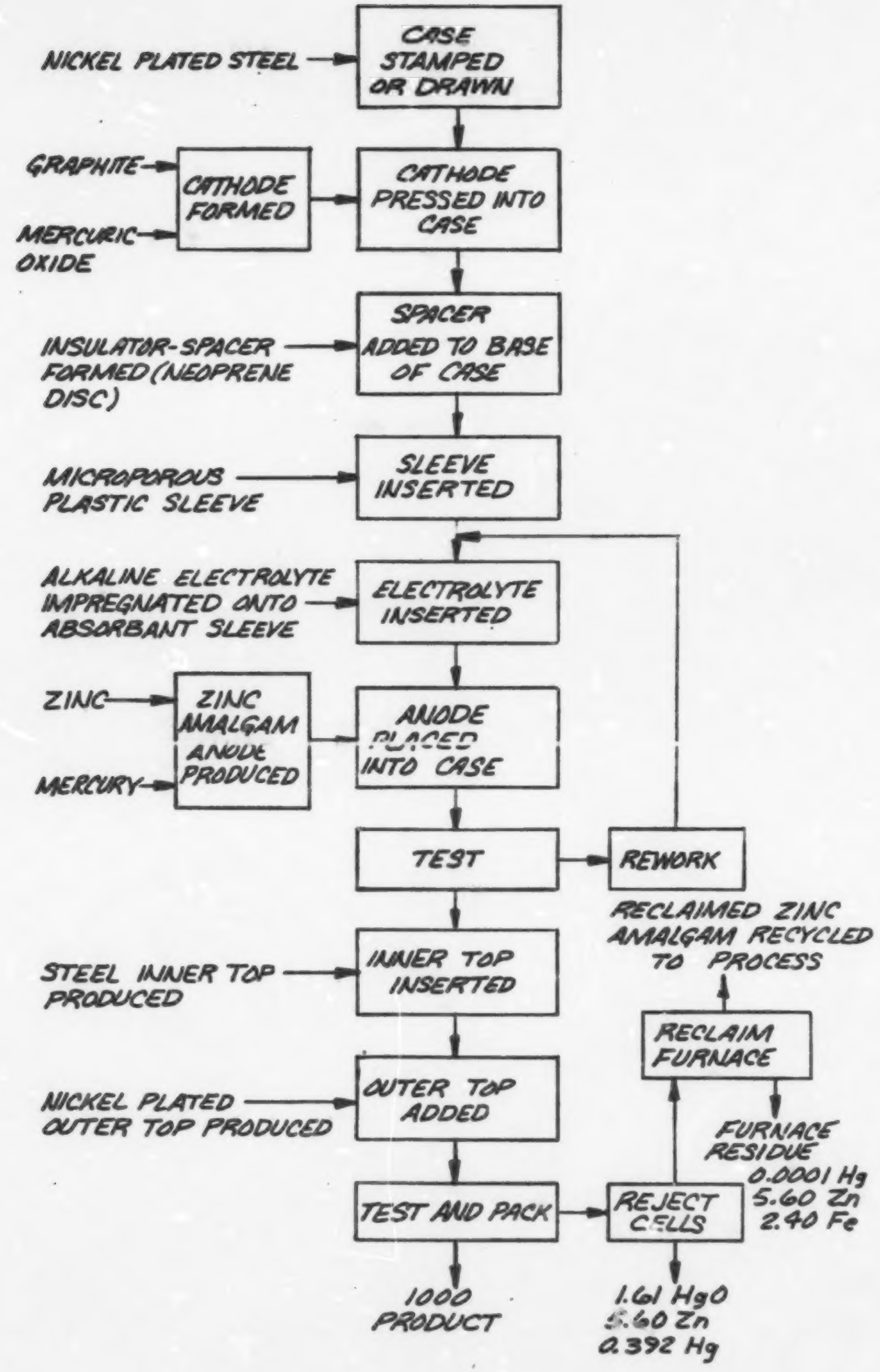

NICKEL PLATED STEEL
CASE STAMPED OR DRAWN
GRAPHITE
MERCURIC OXIDE
CATHODE FORMED
CATHODE PRESSED INTO CASE
INSULATOR-SPACER FORMED (NEOPRENE DISC)
SPACER ADDED TO BASE OF CASE
MICROPOROUS PLASTIC SLEEVE
SLEEVE INSERTED
ALKALINE ELECTROLYTE IMPREGNATED ONTO ABSORBANT SLEEVE
ELECTROLYTE INSERTED
ZINC
MERCURY
ZINC AMALGAM ANODE PRODUCED
ANODE PLACED INTO CASE
TEST
REWORK
RECLAIMED ZINC AMALGAM RECYCLED TO PROCESS
STEEL INNER TOP PRODUCED
INNER TOP INSERTED
RECLAIM FURNACE
NICKEL PLATED OUTER TOP PRODUCED
OUTER TOP ADDED
FURNACE RESIDUE
0.0001 Hg
5.60 Zn
2.40 Fe
TEST AND PACK
REJECT CELLS
1000 PRODUCT
1.61 HgO
5.60 Zn
0.392 Hg

Figure 15. Simplified Diagram of Major Operations in Mercury Battery (Ruben) Manufacture

(Some plants have their own reclaim furnaces, but others send their scrap cells to dealers.) The wastes from rejected batteries are 1.61 kg mercuric oxide, 0.39 kg mercury and 5.60 kg zinc per 1000 kg product. Wastes from the reclaim furnace consist of unreacted residue which is typically deposited in a landfill.

The typical mercury Ruben cell plant produces 453,000 kilograms of cells annually. Wastes from the typical plant consist of mercuric oxide in the amount of 1.61 kg per 1000 kg of product or 729 kg per year, mercury at 0.392 kg per 1000 kg of product or 178 kg per year, and zinc at 5.60 kg per 1000 kg of product or 2537 kg per year. The waste stream consists of 4,530 kg of batteries, 95% of which is reclaimed. Mercury in the amount of 853 kg is sent to reclaim each year, and it is estimated that 95% or 810.5 kg per year is actually reclaimed. The remaining 42.5 kg goes to landfill as does 2537 kg of zinc and 1087 kg of iron in a total waste stream of 3667.5 kg of furnace residue. The typical location of the Ruben cell plant is in the eastern U.S. and the age is 10 years.

The characteristics of the typical mercury cell plant are summarized in Table 16.

The Weston cell differs from the above described Ruben cell in that a cadmium amalgam is used as the anode and mercury metal is used as the cathode. The electrolyte in this case consists of a mixture of cadmium and mercury sulfates. A process flow diagram is shown in Figure 16.

The wastes from this cell are in the form of rejected batteries from the test and package step of the process. The Weston mercury cell typical plant as described in Table 17 produces 906 kg batteries annually. The wastes consist of mercury at 1.854 kg per 1000 kg of product or 1.680 kg per year, mercuric sulfate at 0.618 kg per 1000 kg of product, or 0.560 kg per year, cadmium sulfate at 0.795 kg per 1000 kg of product or 0.720 kg per year,and cadmium at 0.442 kg per 1000 kg of product or 0.400 kg per year. The waste stream consists of about 9 kg batteries per year. The typical location of a Weston cell plant is the northeastern U.S. and its age is approximately 40 years.

Waste factors from the cadmium-mercury primary cell could not be derived from industry sources. However, since these cells are generally produced by the same plants which produce the mercury Ruben cell, one could expect the waste factors for cadmium and mercury to be similar to those for zinc and mercury in the Ruben cell. In general, industry sources have indicated that, like the Ruben cell, the scrap cells containing mercury are reclaimed either on-site or by outside scrap reclaimers.

Table 16. Mercury Cell (Ruben) Typical Plant

A. Annual Production = 453,000 kg of batteries

B. Waste Characterization

1. Mercuric Oxide = 1.61 kg per 1000 kg batteries
= 729 kg per year

2. Mercury = 0.392 kg per 1000 kg batteries
= 178 kg per year

3. Zinc = 5.60 kg per 1000 kg batteries
= 2537 kg per year

C. Waste Stream = 4,530 kg batteries

D. Amount Reclaimed = 853 kg of mercury to reclaim each year
= 810.5 kg of mercury per year (assume 95% reclaimed)

Amount to Landfill = 42.5 kg per year of mercury
= 2537 kg per year of zinc
= 1087 kg per year of iron

Total Waste Stream = 3667.5 kg of furnance residue

E. Typical Location = Eastern U.S.

F. Typical Age = 10 years

G. Number of Employees = 250-500

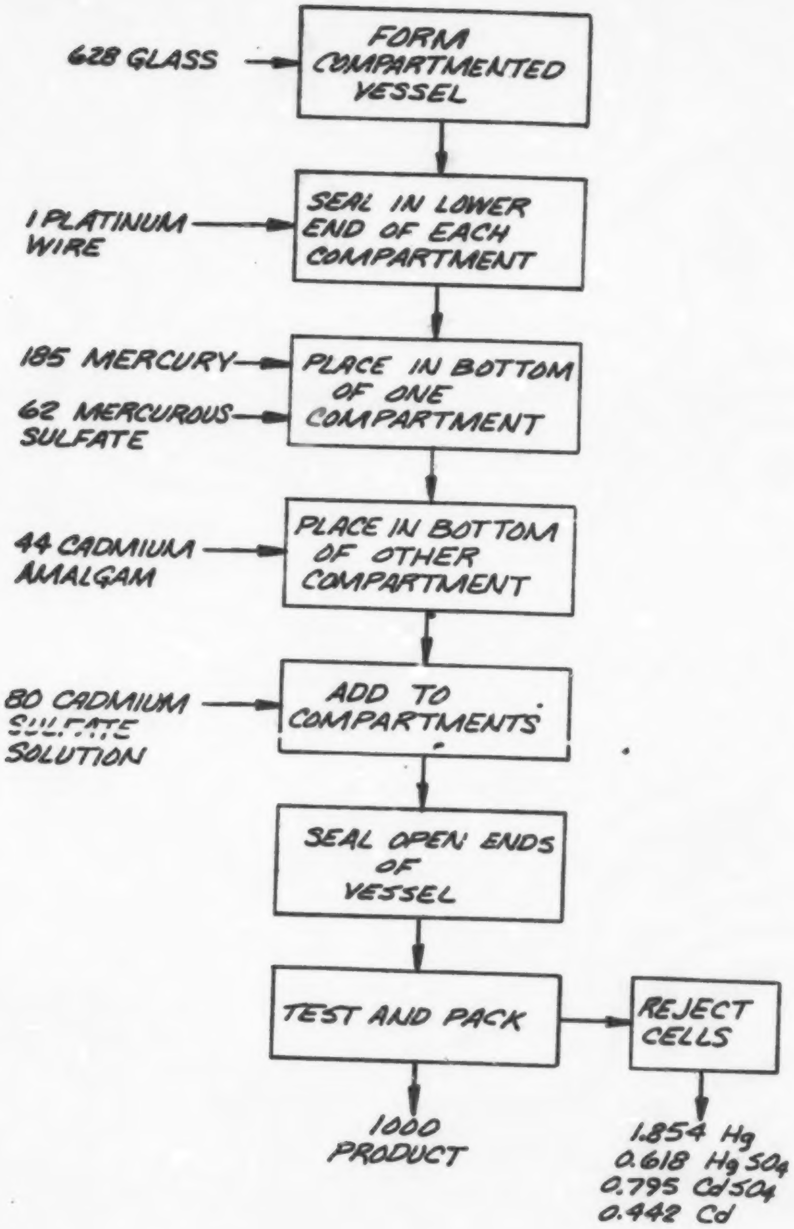

628 GLASS
FORM COMPARTMENTED VESSEL
1 PLATINUM WIRE
SEAL IN LOWER END OF EACH COMPARTMENT
185 MERCURY
62 MERCUROUS SULFATE
PLACE IN BOTTOM OF ONE COMPARTMENT
44 CADMIUM AMALGAM
PLACE IN BOTTOM OF OTHER COMPARTMENT
80 CADMIUM SULFATE SOLUTION
ADD TO COMPARTMENTS
SEAL OPEN ENDS OF VESSEL
TEST AND PACK
REJECT CELLS
1000 PRODUCT
1.854 Hg
0.618 HgSO4
0.795 CdSO4
0.442 Cd

Figure 16. Simplified Diagram of Major Operations in Weston Standard Mercury Cell Manufacture

Table 17. Mercury Cell (Weston) Typical Plant

A. Annual Production = 906 kg of batteries

B. Waste Characterization

1. Mercury = 1.854 kg per 1000 kg batteries
   = 1.680 kg per year

2. Mercuric Sulfate = 0.618 kg per 1000 kg batteries
   = 0.560 kg per year

3. Cadmium Sulfate = 0.795 kg per 1000 kg batteries
   = 0.720 kg per year

4. Cadmium = 0.442 kg per 1000 kg batteries
   = 0.400 kg per year

C. Waste Stream = 9 kg of batteries

D. Typical Location = Northeastern U.S.

E. Typical Age = 40 years

The waste mercuric oxide, mercury, zinc, mercuric sulfate, cadmium sulfate, and cadmium from the production of Ruben, Weston, and cadmium-mercury cells are considered potentially hazardous when destined for land disposal. The potential for release of hazardous materials from these wastes, particularly soluble mercury and cadmium, necessitates the categorization of these wastes into the severely hazardous group.

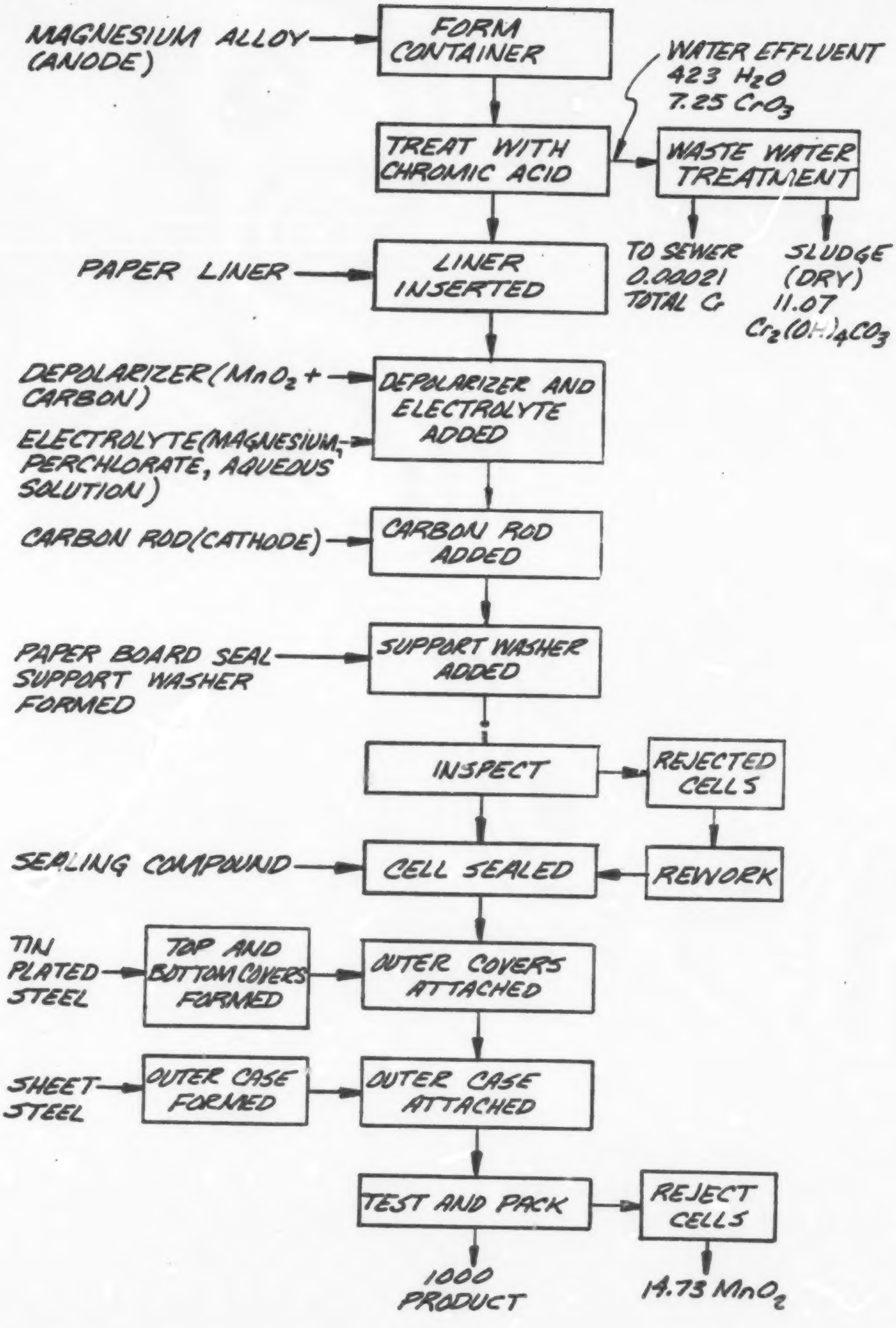
The typical Ruben cell plant was based on data from three plants representing 56% of Ruben mercury cell production in the U.S. The waste factors were computed from quantities of wastes supplied by the plants. A rejection rate of 1% was assumed to compute the total waste stream. The amounts of waste materials reclaimed and the composition of the mercury reprocessing furnace residue were estimated. The typical Weston cell plant was based on one plant in the U.S. currently producing the cells. No typical plant was derived for the cadmium-mercury cell due to the lack of information from industry sources, but it is believed to have characteristics quite similar to the Ruben mercury cell plant.

5.3.5 Magnesium-Carbon Dry Cell

The manufacturing process for the magnesium-carbon cell begins with the fabrication of a magnesium alloy container which serves as the anode. The container is cleaned and treated with chromic acid for corrosion resistance and a paper liner is inserted. The depolarizer of manganese dioxide and carbon and the electrolyte of magnesium perchlorate are then added. The cathode carbon rod is added to the container and is supported by a paperboard washer. An inspection step then takes place before the container is sealed with a plastic sealing compound. The tin plated steel top and bottom covers are formed and attached to the cell, and a steel outer case completes the assembly. Quality control testing takes place before the cells are packed for shipment. A process flow diagram is shown in Figure 17.

The wastes from the production of this battery consist of quality control rejected cells containing manganese dioxide at 14.73 kg per 1000 kg of product and water effluent treatment sludges of 11.07 kg of chromium hydroxy carbonate per 1000 kg of product.

The typical magnesium carbon dry cell plant summarized in Table 18 produces 1,359,000 kg of batteries annually. The wastes from the typical plant are manganese dioxide in the amount of 14.73 kg per 1000 kg of product or 20,000 kg per year, chromium hydroxy carbonate at 11.07 kg per 1000 kg of dry product or 15,000 kg per year, and chromium at 0.00021 kg per 1000 kg of product or 0.185 kg per year in the wastewater effluent. The scrap battery waste stream of the typical plant contains approximately 40,770 kg of batteries. The sludge waste stream is estimated to be 37,500 kg per year. The typical location of this type of plant is the eastern U.S., and the typical age is approximately 15 years.



MAGNESIUM ALLOY (ANODE)
FORM CONTAINER
WATER EFFLUENT
423 H_2O
7.25 CrO_3
TREAT WITH CHROMIC ACID
WASTE WATER TREATMENT
TO SEWER
0.00021
TOTAL Cr
SLUDGE (DRY)
11.07
$Cr_2(OH)_4CO_3$
PAPER LINER
LINER INSERTED
DEPOLARIZER (MnO_2 + CARBON)
ELECTROLYTE (MAGNESIUM PERCHLORATE, AQUEOUS SOLUTION)
DEPOLARIZER AND ELECTROLYTE ADDED
CARBON ROD (CATHODE)
CARBON ROD ADDED
PAPER BOARD SEAL SUPPORT WASHER FORMED
SUPPORT WASHER ADDED
INSPECT
REJECTED CELLS
SEALING COMPOUND
CELL SEALED
REWORK
TIN PLATED STEEL
TOP AND BOTTOM COVERS FORMED
OUTER COVERS ATTACHED
SHEET STEEL
OUTER CASE FORMED
OUTER CASE ATTACHED
TEST AND PACK
REJECT CELLS
1000 PRODUCT
14.73 MnO_2

Figure 17. Simplified Diagram of Major Operations in Magnesium-Carbon Dry Cell Manufacture

Table 18. Magnesium-Carbon Typical Plant

A. Annual Production = 1,359,000 kg batteries

B. Waste Characterization

1. Manganese Dioxide = 14.73 kg per 1000 kg of batteries
   = 20,000 kg per year

2. Sludge from treatment of chromic acid wastewater as:

   $Cr_2(OH)_4CO_3$ = 11.07 kg per 1000 kg of batteries
   = 15,000 kg per year

3. Total Cr to effluent = 0.00021 kg per 1000 kg of batteries
   = 0.285 kg per year

C. Waste Stream

1. Scrap cells = 40,770 kg

2. Sludge (40% solids basis) = 37,500 kg

D. Typical Location = Eastern U.S.

E. Typical Age = 15 years

F. Number of Employees = 250-500

The waste trivalent chrome containing sludge from the production of magnesium carbon dry cells may be potentially hazardous when destined for land disposal. The degree of hazardousness of this waste is discussed in Appendix A.

The typical plant was derived from data supplied by two plants representing 78% of the U.S. production of magnesium carbon dry cells. The waste factors were computed and production weighted from the quantities of wastes supplied by the plants. The rejected battery waste stream was calculated by assuming a 3% rejection rate. The sludge waste stream was estimated to contain 40% solids by weight.

5.3.6 Zinc-Silver Oxide Dry Cell

The manufacture of the zinc-silver oxide cell begins with the fabrication of a nickel plated steel case. Silver oxide and graphite form the cathode which is then pressed into the case. A neoprene disc serves as the insulator-spacer which is added to the base of the case. A microporous plastic sleeve is then inserted and impregnated with the potassium hydroxide electrolyte. Next a zinc amalgam anode is formed and placed in the case. Preliminary testing is then performed before final assembly. The cell is sealed with a tin plated steel inner top and a nickel plated bottom before final testing and packaging.

This cell is a widely produced miniature battery produced in a similar fashion to the mercury (Ruben) cell. A mercury zinc amalgam is used as the anode material and a silver oxide-carbon material is used as the cathode. The electrolyte and depolarizer is a paste containing silver oxide and potassium hydroxide.

The wastes from this process are in the form of rejected batteries from the test and package step of the process diagram shown in Figure 18. The wastes from the rejected batteries are 0.00109 kg of mercury, 0.0187 kg of zinc, and 0.0047 kg of silver oxide per 1000 kg of product. The waste cells from this production contain valuable materials and are sold to outside scrap reclaimers. Industry sources indicate that there are no hazardous wastes destined for land disposal from the production of this battery.

The typical zinc-silver oxide plant summarized in Table 19 produces 59,100 kg of cells annually. Wastes from the typical plant include mercury in the amount of 0.00109 kg per 1000 kg of product or 0.064 kg per year, zinc at 0.0187 kg per 1000 kg of product or 1.105 kg per year, and silver oxide at 0.0047 kg per 1000 kg of product or 0.28 kg per year. The waste stream of the typical plant contains 591 kg of batteries per year.

The typical plant was derived from the data supplied by one plant representing 14% of U.S. production of zinc-silver oxide cells. The waste factors were computed from the quantities of wastes supplied by the plant. A rejection rate of 1% was estimated to determine the waste stream of the typical plant.

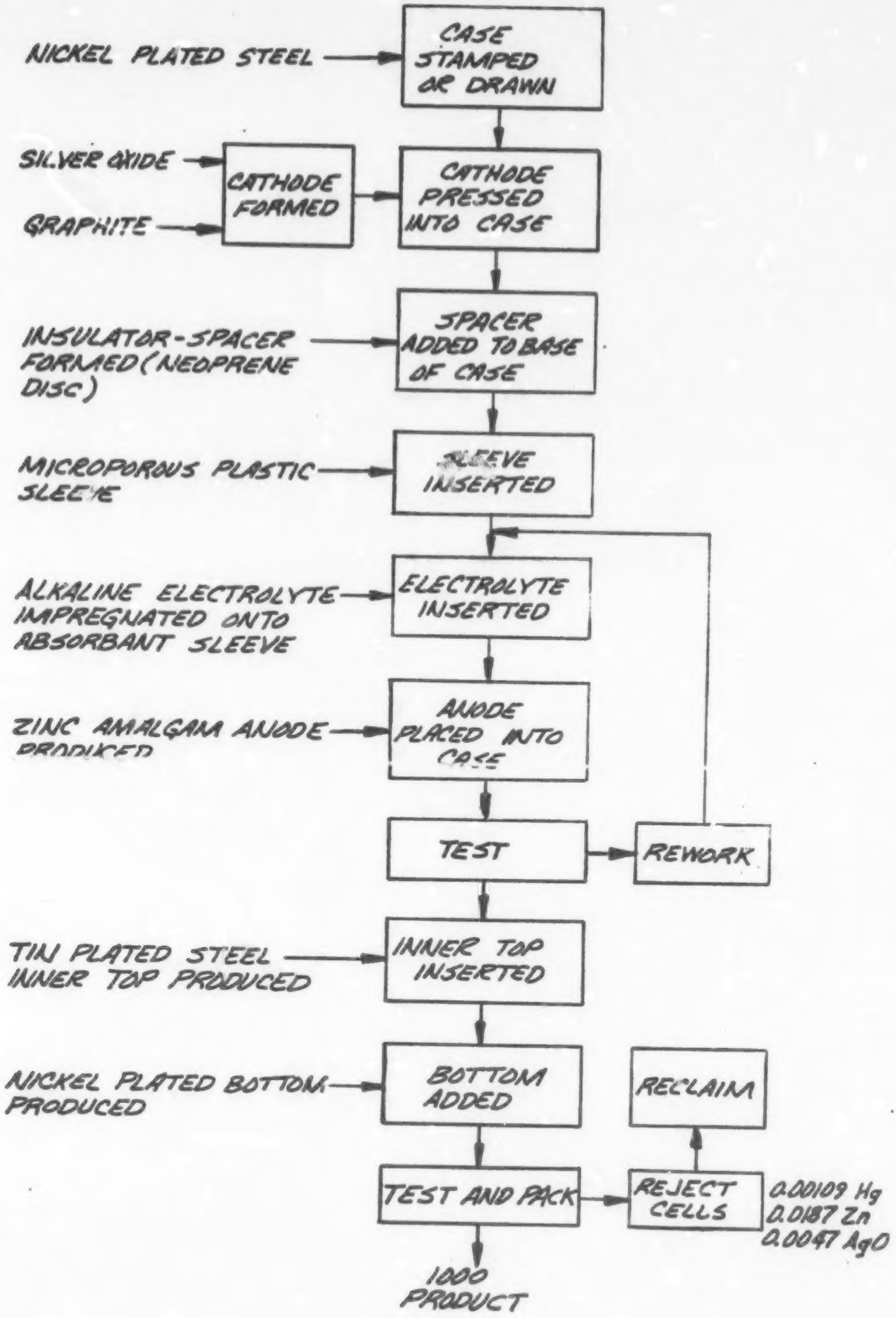

NICKEL PLATED STEEL
CASE STAMPED OR DRAWN
SILVER OXIDE
GRAPHITE
CATHODE FORMED
CATHODE PRESSED INTO CASE
INSULATOR-SPACER FORMED (NEOPRENE DISC)
SPACER ADDED TO BASE OF CASE
MICROPOROUS PLASTIC SLEEVE
SLEEVE INSERTED
ALKALINE ELECTROLYTE IMPREGNATED ONTO ABSORBANT SLEEVE
ELECTROLYTE INSERTED
ZINC AMALGAM ANODE PRODUCED
ANODE PLACED INTO CASE
TEST
REWORK
TIN PLATED STEEL INNER TOP PRODUCED
INNER TOP INSERTED
NICKEL PLATED BOTTOM PRODUCED
BOTTOM ADDED
RECLAIM
TEST AND PACK
REJECT CELLS
0.00109 Hg
0.0187 Zn
0.0047 AgO
1000 PRODUCT

Figure 18. Major Operations in Zinc-Silver Oxide Dry Cell Manufacture

Table 19. Zinc-Silver Oxide Dry Cell Typical Plant

A. Annual Production = 59,100 kg per year

B. Waste Characterization

1. Mercury = 0.00109 kg per 1000 kg batteries
= 0.064 kg per year

2. Zinc = 0.0187 kg per 1000 kg batteries
= 1.105 kg per year

3. Silver Oxide = 0.0047 kg per 1000 kg batteries
= 0.28 kg per year

C. Waste Stream = 591 kg batteries

D. Typical Location = Entire United States

E. Typical Age = 1-5 years

F. Number of Employees = 100-250

5.3.7 Lead Reserve Cell

The lead-acid reserve cell is a limited production item designed solely for military use. There are currently only two producers in the U.S., and the production of this cell varies widely with military requirements. The average annual production of these batteries over the last ten years has been approximately 113,500 kg per year. (19)

The battery is produced in the following way: A steel shim stock (0.076 mm) is plated with a thin coating of nickel on both sides, and the plated sheet is then rinsed and plated on both sides with about 0.025 mm of lead and rinsed again. One side of the lead plated sheet is then anodized to lead oxide. The sheet is stamped and the cell formed over a mandrel. A glass ampule containing fluoboric acid is inserted, and the cell sealed with a vinyl or other plastic covering. A simplified process flow chart for the production of this battery is shown in Figure 19.

The potentially hazardous wastes from the production of lead-acid reserve cells come from quality control rejected batteries, scrap metals, and possibly from future wastewater sludges from wastewater treatment for nickel and lead in the plant effluent. At the present time, one plant has a wastewater treatment system in the planning stages, but now the effluent goes to a municipal sewage system. The wastes from rejected batteries and scrap consists of 182 kg of lead and 104 kg of nickel per 1000 kg of product. A typical plant characterization is given in Table 20.

The wastes from the typical plant include lead and nickel metal from production scrap and rejected batteries, and wastewater treatment sludges containing lead and nickel compounds, probably as the hydroxides. All of these metals and compounds must be considered potentially hazardous (to differing degrees when destined for land disposal) due to the possibility of leaching from a landfill into the water table. The degree of hazardousness and related properties of these materials are discussed in Appendix A.

The typical plant was based upon data supplied by one plant producing over 90% of the U.S. production of lead-acid reserve cells. The waste factors for rejected cells and production scrap were calculated from data supplied by this plant. The wastewater treatment sludges were estimated by the contractor based upon the ratio of scrap rates in the plant and the nature of the sludges obtained from wastewater treatment of electroplating operations.

5.3.8 Low Temperature Carbon-Zinc Dry Cell

The production of the low temperature dry cell begins by shaping a container from a zinc alloy sheet. A separator of paper board coated with a paste containing mercuric chloride is then inserted into the container. The separator is followed by a

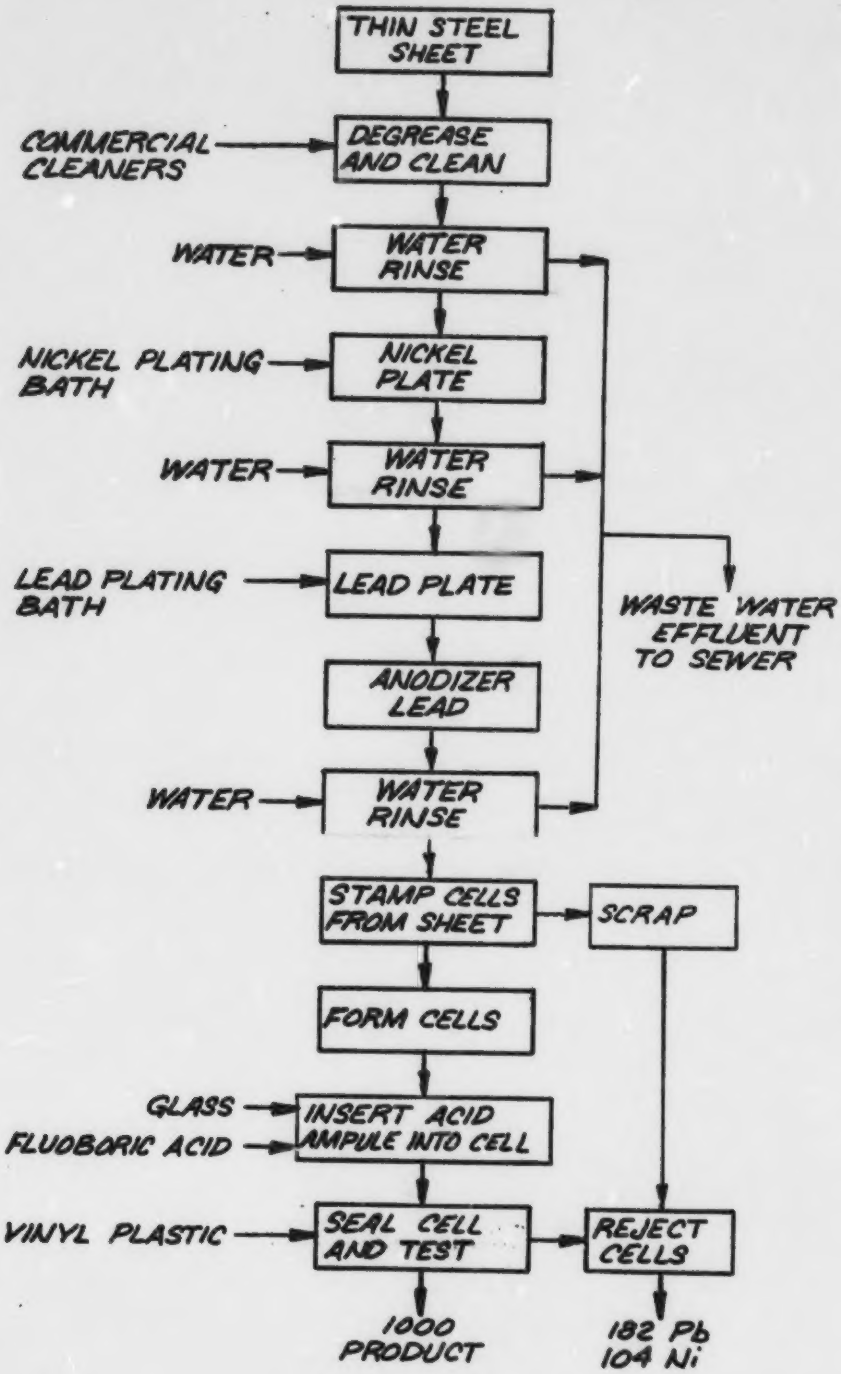

THIN STEEL SHEET
COMMERCIAL CLEANERS
DEGREASE AND CLEAN
WATER
WATER RINSE
NICKEL PLATING BATH
NICKEL PLATE
WATER
WATER RINSE
LEAD PLATING BATH
LEAD PLATE
WASTE WATER EFFLUENT TO SEWER
ANODIZER LEAD
WATER
WATER RINSE
STAMP CELLS FROM SHEET
SCRAP
FORM CELLS
GLASS
FLUOBORIC ACID
INSERT ACID AMPULE INTO CELL
VINYL PLASTIC
SEAL CELL AND TEST
REJECT CELLS
1000 PRODUCT
182 Pb
104 Ni

Figure 19. Simplified Diagram of Major Operations in Lead Acid Reserve Cell Manufacture

Table 20. Lead-Fluoboric Acid Reserve Cell Typical Plant

A. Annual Production = 45,400 kg of batteries

B. Waste Characterization

1. Lead = 182 kg per 1000 batteries
   = 8,263 kg per year in scrap and batteries

2. Nickel = 104 kg per 1000 kg of batteries
   = 4,722 kg per year in scrap and batteries

C. Waste Stream

1. Rejected scrap and batteries = 14,982 kg per year

2. Wastewater treatment sludges containing lead and nickel (est.) = 130 kg per year (dry basis)
   = 371 kg per year (35% solids basis)

D. Typical Location = Eastern United States

E. Typical Age = Approximately 30 years

depolarizer of manganese dioxide and carbon black and an electrolyte of methylamine hydrochloride, calcium chloride and lithium chloride. A carbon rod current collector is inserted into the container and is held by a paperboard support washer. The cell undergoes a quality control inspection before it is sealed. The top and botton covers of tin plated steel are formed and attached to the cell. An outer case of steel or paper is decorated, formed, and attached to the cell, and an electrical testing step takes place before the product is packaged for shipment.

This specialty battery is a limited production item which is produced in an identical fashion to the standard carbon-zinc dry cell with the substitution of non-freezing electrolytes in place of the zinc and ammonium chloride. The wastes are in the form of rejected batteries from the test and package step of the process diagram in Figure 20. The wastes contained in the battery rejects are 0.0073 kg mercury, 3.81 kg zinc, 6.15 kg manganese dioxide, 0.001 kg barium chromate, 0.00027 kg cadmium and 0.00031 lead per 1000 kg production.

The waste mercury, zinc, barium chromate, cadmium and lead are considered potentially hazardous to varying degrees when destined for land disposal. The hazardousness of these wastes and related properties are contained in Appendix A.

A typical plant could not be constructed for this battery due to its limited production and military applications. The wastes are included in the figures for the carbon-zinc dry cell.

5.3.9 Zinc-Silver Chloride Cell

The zinc-silver chloride cell is included here only for the sake of completeness as industry sources have indicated that it is no longer being produced.

The fabrication of zinc-silver chloride cells began by shaping a container from a zinc alloy sheet. A separator of paperboard coated with a paste containing mercuric chloride was then inserted into the container. The separator was followed by a depolarizer of a silver chloride paste and an electrolyte of ammonium chloride and zinc chloride. A carbon rod current collector was inserted into the container and held by a paperboard support washer. The cell underwent a quality control inspection before it was sealed with an asphalt compound. Top and bottom covers of tin plated steel were formed and an outer case of paper was decorated, formed, and fitted to the container. An electrical testing step took place before the product was packaged for shipment.

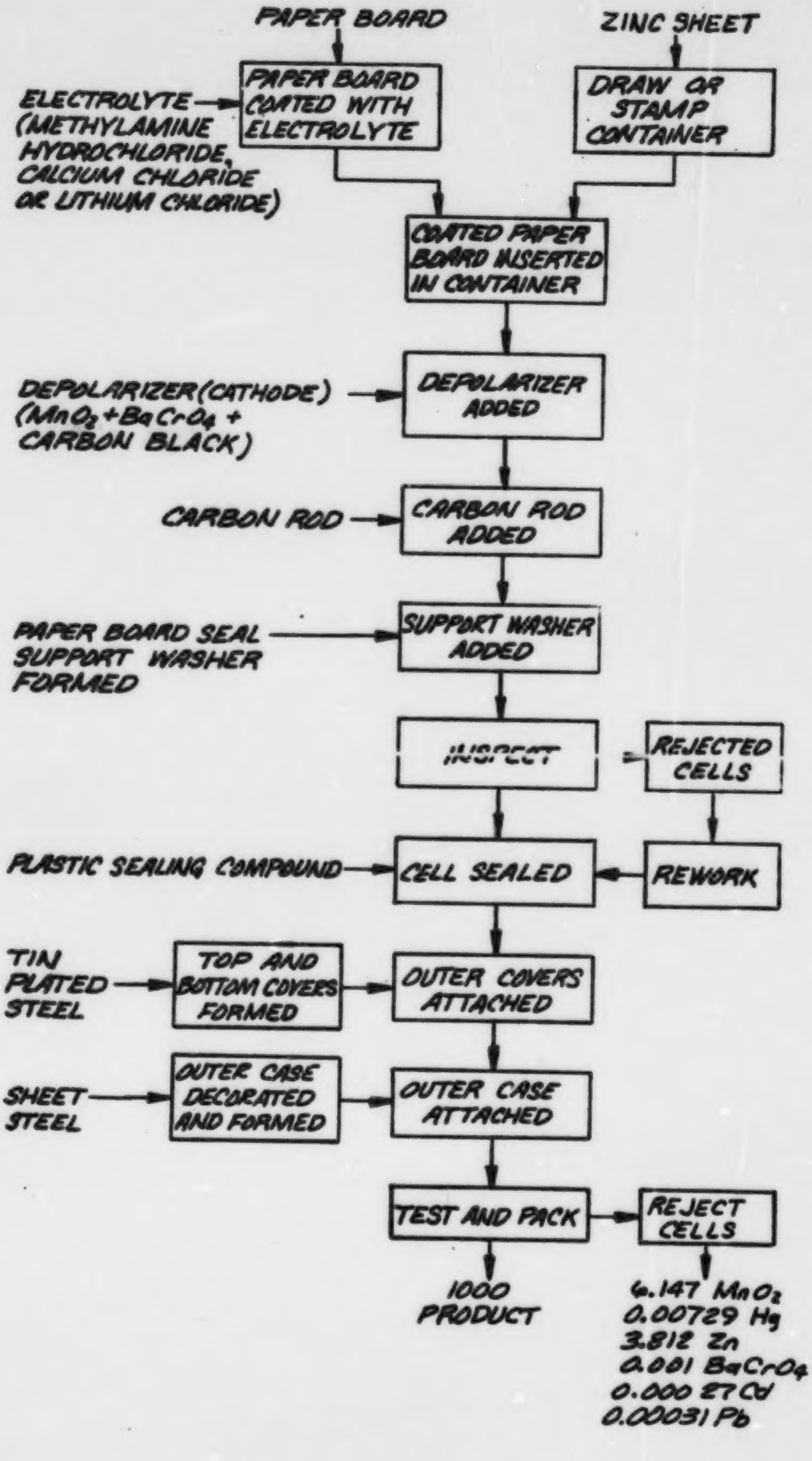

PAPER BOARD
ZINC SHEET
ELECTROLYTE (METHYLAMINE HYDROCHLORIDE, CALCIUM CHLORIDE OR LITHIUM CHLORIDE)
PAPER BOARD COATED WITH ELECTROLYTE
DRAW OR STAMP CONTAINER
COATED PAPER BOARD INSERTED IN CONTAINER
DEPOLARIZER (CATHODE) ($MnO_2 + BaCrO_4$ + CARBON BLACK)
DEPOLARIZER ADDED
CARBON ROD
CARBON ROD ADDED
PAPER BOARD SEAL SUPPORT WASHER FORMED
SUPPORT WASHER ADDED
INSPECT
REJECTED CELLS
PLASTIC SEALING COMPOUND
CELL SEALED
REWORK
TIN PLATED STEEL
TOP AND BOTTOM COVERS FORMED
OUTER COVERS ATTACHED
SHEET STEEL
OUTER CASE DECORATED AND FORMED
OUTER CASE ATTACHED
TEST AND PACK
REJECT CELLS
1000 PRODUCT
6.147 MnO_2
0.00729 Hg
3.812 Zn
0.001 $BaCrO_4$
0.000 27 Cd
0.00031 Pb

Figure 20. Simplified Diagram of Major Operations in Low Temperature Carbon-Zinc Cell Manufacture

The zinc-silver chloride cell was a specialty battery which was produced in a fashion similar to that of the carbon-zinc dry cell. This latter cell contained a zinc container anode, a paste type electrolyte consisting of zinc and ammonium chloride, and a cathode of carbon rod. The depolarizer was composed of a silver chloride paste. A process flow diagram is given in Figure 21.

5.3.10 Magnesium-Silver and Copper Chloride Cells

Manufacture of the magnesium-silver chloride cell begins with the electrolytic coating of silver foil with a silver chloride solution forming the cathode. A magnesium foil serves as the anode. Leads are welded on the electrodes and dry absorbent paper is inserted between them. Two configurations of the cell are generally manufactured: a flat cell designed to deliver maxium voltage with limited capacity, and a cylindrical cell for high capacity with low voltage output. Flat cells are formed by stacking electrode assemblies and sealing the cell in a stainless steel case with a dessicant. The cylindrical cells are formed by winding the electrode assembly spirally and sealing in a stainless steel case with a dessicant. Both types of cell are then ready for packing and shipping.

The manufacture of the magnesium copper chloride cell is similar except for the substitution of copper foil and copper chloride in the cathode.

The magnesium silver chloride cell generally yields better performance than the copper chloride cell, but its cost is also higher.

The simplified process flow diagrams for the fabrication of these cells are shown in Figures 22 and 23.

The wastes from the production of these batteries consist of rejected and scrap batteries containing silver chloride and copper chloride. Industry sources have indicated that little (if any) of this scrap goes to land disposal.

5.3.11 Thermal Cell Primary Battery

This battery is a very specialized and limited production type cell. It is produced exclusively for military applications by four companies in the U.S. These cells are characterized by producing a high current discharge for a short period of time by operating at an elevated temperature. The elevated temperature is generated by a pyrotechnic device within the battery, which melts a salt electrolyte and produces a

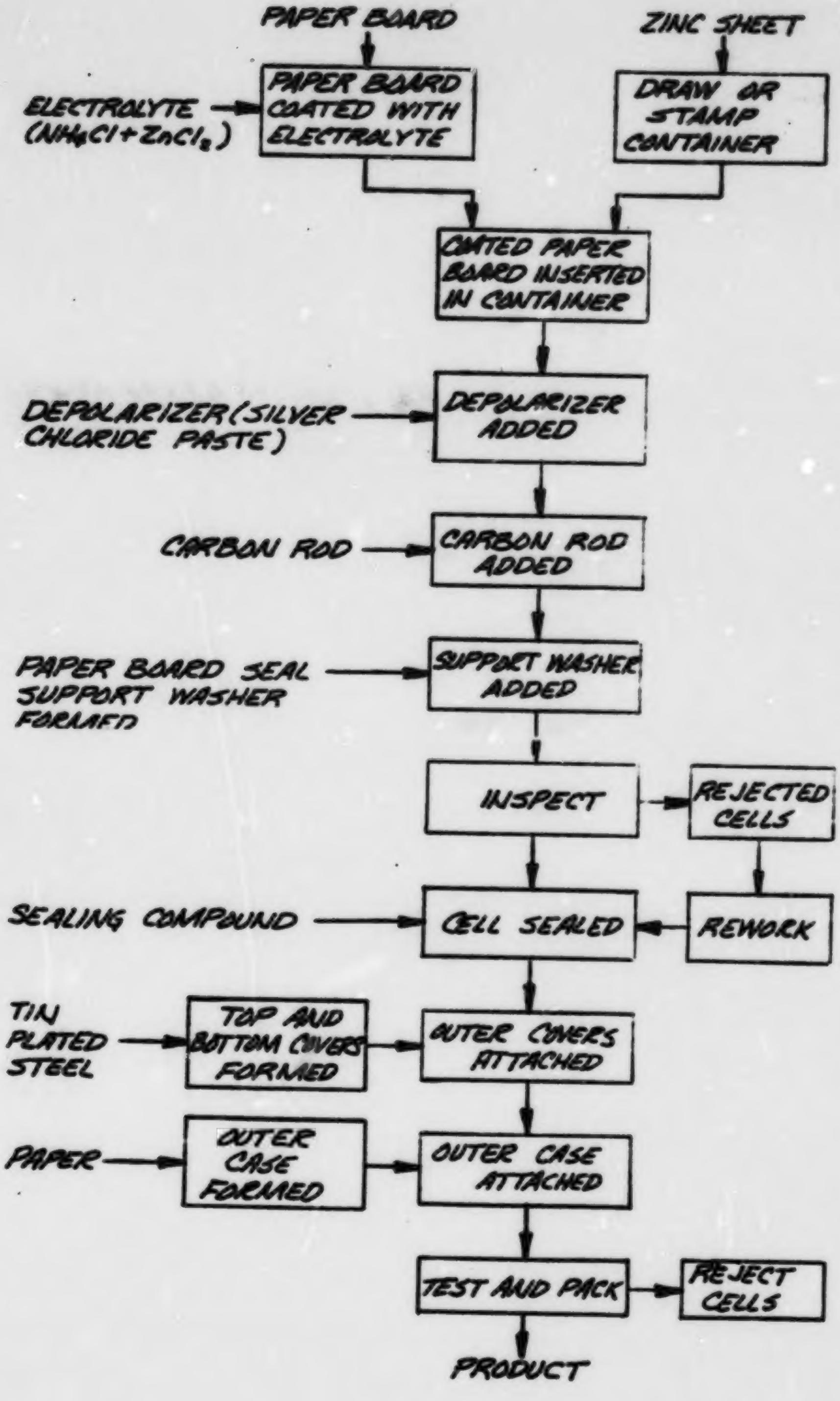

PAPER BOARD
ZINC SHEET
ELECTROLYTE (NH4Cl + ZnCl2)
PAPER BOARD COATED WITH ELECTROLYTE
DRAW OR STAMP CONTAINER
COATED PAPER BOARD INSERTED IN CONTAINER
DEPOLARIZER (SILVER CHLORIDE PASTE)
DEPOLARIZER ADDED
CARBON ROD
CARBON ROD ADDED
PAPER BOARD SEAL SUPPORT WASHER FORMED
SUPPORT WASHER ADDED
INSPECT
REJECTED CELLS
SEALING COMPOUND
CELL SEALED
REWORK
TIN PLATED STEEL
TOP AND BOTTOM COVERS FORMED
OUTER COVERS ATTACHED
PAPER
OUTER CASE FORMED
OUTER CASE ATTACHED
TEST AND PACK
REJECT CELLS
PRODUCT

Figure 21. Simplified Diagram of Major Operations in Zinc-Silver Chloride Dry Cell Manufacture

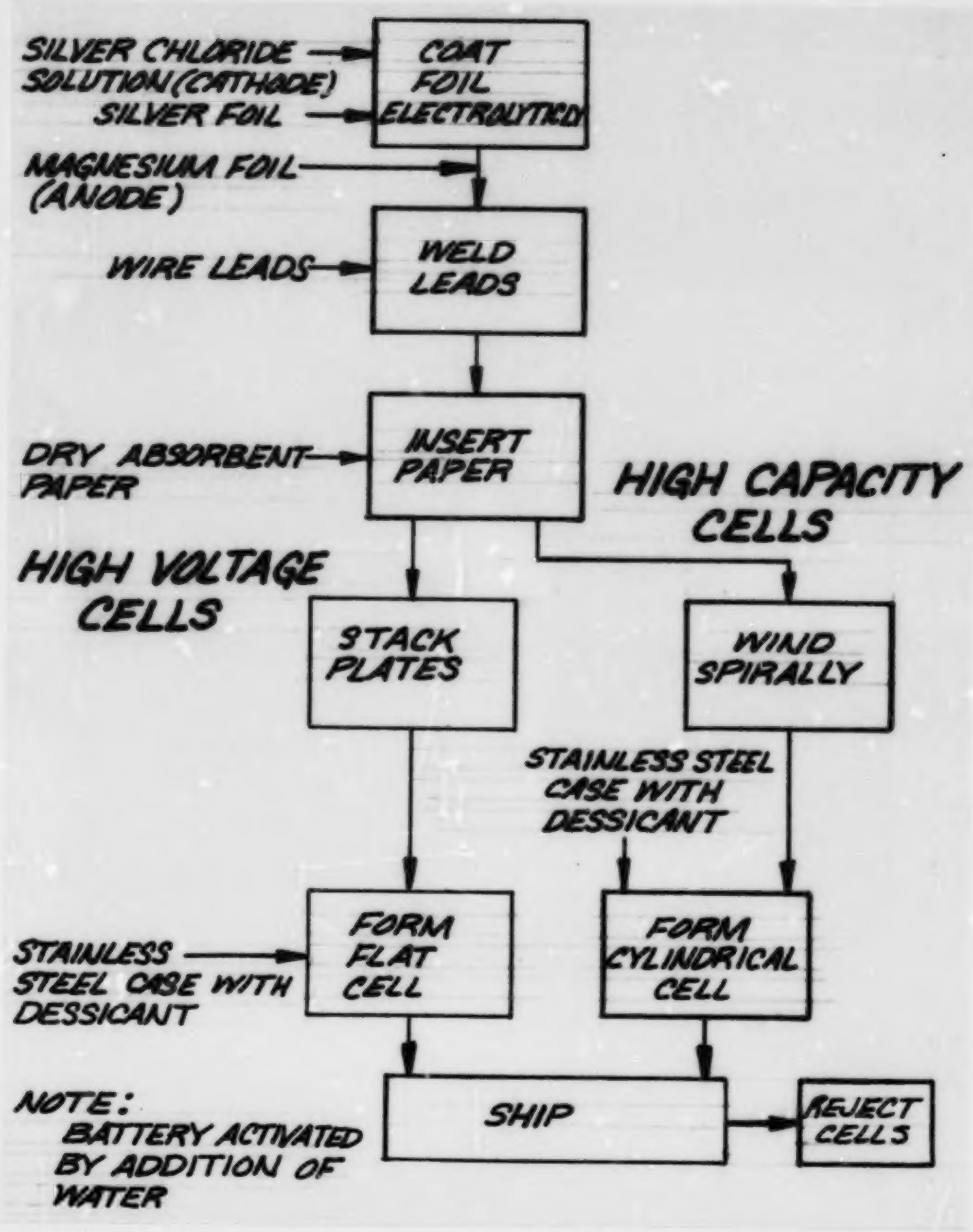

SILVER CHLORIDE SOLUTION (CATHODE)
SILVER FOIL
COAT FOIL ELECTROLYTICL
MAGNESIUM FOIL (ANODE)
WIRE LEADS
WELD LEADS
DRY ABSORBENT PAPER
INSERT PAPER
HIGH CAPACITY CELLS
HIGH VOLTAGE CELLS
STACK PLATES
WIND SPIRALLY
STAINLESS STEEL CASE WITH DESSICANT
STAINLESS STEEL CASE WITH DESSICANT
FORM FLAT CELL
FORM CYLINDRICAL CELL
NOTE: BATTERY ACTIVATED BY ADDITION OF WATER
SHIP
REJECT CELLS

Figure 22. Simplified Diagram of Major Operations in Magnesium-Silver Chloride Reserve Dry Cell Manufacture

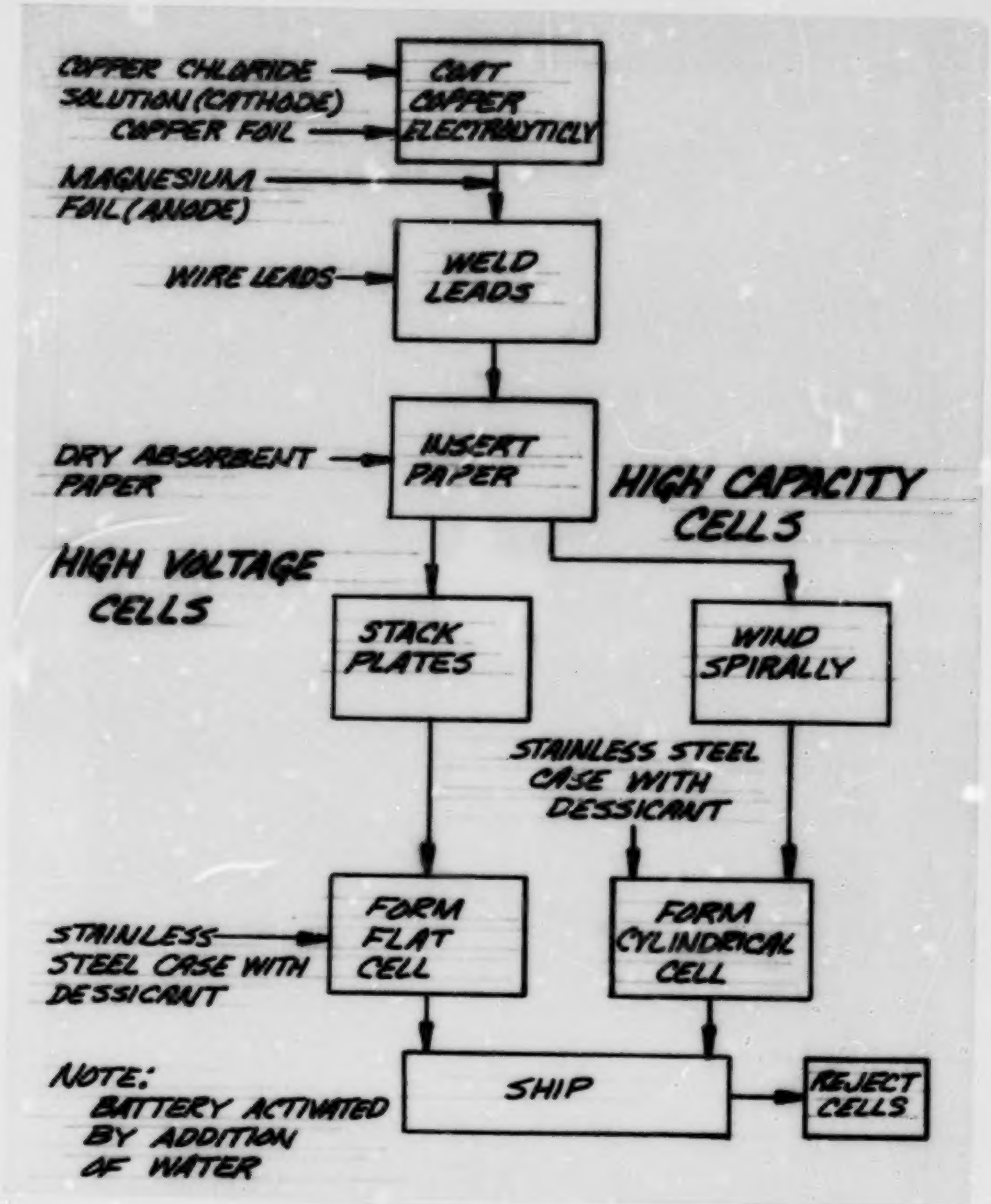

COPPER CHLORIDE SOLUTION (CATHODE)
COPPER FOIL
COAT COPPER ELECTROLYTICLY
MAGNESIUM FOIL (ANODE)
WIRE LEADS
WELD LEADS
DRY ABSORBENT PAPER
INSERT PAPER
HIGH CAPACITY CELLS
HIGH VOLTAGE CELLS
STACK PLATES
WIND SPIRALLY
STAINLESS STEEL CASE WITH DESSICANT
STAINLESS STEEL CASE WITH DESSICANT
FORM FLAT CELL
FORM CYLINDRICAL CELL
SHIP
REJECT CELLS
NOTE: BATTERY ACTIVATED BY ADDITION OF WATER

Figure 23. Simplified Diagram of Major Operations in Magnesium-Copper Chloride Reserve Dry Battery Manufacture

current for the period of time the electrolyte remains molten. The electrolyte contains lithium chloride, potassium chloride, and a small amount of calcium chromate. The anode materials are either vanadium, calcium,or tungsten oxide. The cathode is usually nickel and the battery insulators are often asbestos. There are two types of pyrotechnic devices used inside the battery. The first type is a zirconium metal-based system containing a barium chromate oxidizer and the second is an iron metal-based system with a potassium perchlorate oxidizer and calcium chromate. The chromates are estimated to be 5 to 7% of the total battery weight. The disposal of spent batteries is carried out by the military, and generally accomplished by breaking them up in a hammer mill and allowing them to burn in open air. (19)

5.3.12 Nuclear Battery

This battery is an extremely specialized item produced only for the Defense Department, the National Aeronautics and Space Administration, or the Atomic Energy Commission. The quantity of production of this battery is classified as are the fabrication procedures, but the amount of production is very limited. The nuclear material, plutonium, is a hazardous waste product from the battery. The disposal of the waste product is carefully controlled by the Atomic Energy Commission.

5.3.13 Lithium Primary Cell

The lithium cell has been described as the primary battery of the future, for it has several advantages over existing primary batteries. These advantages include higher voltage, longer shelf life, low temperature performance, high capacity,and greater power densities. These batteries are still in the development stage by a number of companies in the U.S., but one company is currently producing this battery commercially in limited quantities.

In general, these batteries contain lithium metal as the anode (usually in the form of a mesh screen) and graphite, fluorinated graphite, vanadium pentoxide, or sulfur dioxide as the cathode. The electrolytes are primarily of the non-aqueous type — due to the fact that lithium reacts vigorously with water to generate hydrogen, gas,and heat. The electrolytes are usually organic or inorganic liquids containing no water, but containing dissolved salts. The electrolytes which have been used include — methyl formate, propylene carbonate,and thionyl chloride. The salts used in the electrolyte include — lithium chloride, lithium perchlorate,and phosphorous oxychlorate. (20).

Although this battery is only in limited production at the present time, there are a number of possible environmental and safety problems concerning disposal of scrap cells. The lithium metal is capable of reacting quite vigorously with moisture or oxidizing agents creating a possible fire or explosion hazard. Many of the electrolytes and cathode depolarizers contain potentially hazardous materials. There is also the danger of igniting the lithium metal to produce an extremely hot flame if the scrap cells were incinerated. Due to the proprietary nature of these batteries, the types and quantities of hazardous wastes can not be projected in any meaningful way at the present time.

5.4 Summary of Waste Streams Containing Potentially Hazardous Constituents

In this section are summarized the waste streams containing potentially hazardous materials resulting from the manufacture of storage and primary batteries destined for land disposal. These wastes streams will be presented under the separate categories of the industries.

5.4.1 SIC 3691, Storage Batteries Waste Streams Summary

5.4.1.1 Lead-Acid Battery

The wastes from lead-acid battery production include the following:

(a) Wastes produced from the manufacture of grid materials. These will include dusts, dross,and rejects of the raw materials and alloys used. This waste amounts to 30 kg per 1000 kg of product comprised of lead and lead alloys.

(b) Wastes produced from the cathode and anode paste preparations. This waste amounts to about 2 kg per 1000 kg of product as lead and lead oxide paste.

(c) Wastes produced from clean-up of the pasting area. This amounts to 5 kg per 1000 kg of product in the form of lead oxide and lead powders suspended in a water effluent of about 750 kg of water.

(d) Wastes produced from reject plates in the curing cycle. These wastes generally consist of 10 kg of lead monoxide and 20 kg of lead per 1000 kg of product.

(e) Wastes produced from reject assembled elements. These rejects consist of 10 kg of lead monoxide and 20 kg of lead per 1000 kg of product.

(f) Wastewater solutions. These are water-borne raw wastes comprised of sulfuric acid (typically 2 to 4%) in water containing suspended and dissolved lead. The sources of lead containing wastewater include the pasting area, the dry and wet charge forming areas, and the assembled battery washing area. Also, in cases where a battery breaker is located on site with the battery plant, there will be an additional wastewater stream. A typical plant producing 20% wet charge and 80% dry charge batteries would have a lead raw waste factor of 0.331 kg of lead (suspended and dissolved) per 1000 kg of product.

(g) Sludges recovered from treatment of wastewater streams. These wastes consist of lead hydroxide and lead sulfate at 0.541 kg per 1000 kg of product (80% solids basis) for those plants using sodium hydroxide neutralization. The composition of the sludge typically will include lead sulfate (0.293 kg per 1000 kg), lead hydroxide (0.140 kg per 1000 kg) with a water content ranging from 20 to 65%. For those plants using lime neutralization, a calcium sulfate sludge is produced of 735 kg (dry basis) per 1000 kg of product. The composition of the sludge typically will include calcium sulfate (2101 kg per 1000 kg at 35% solids basis), lead hydroxide (0.140 kg per 1000 kg), lead sulfate (0.293 kg per 1000 kg) with a lead content of approximately 150 mg per liter.

Information received from a number of large and small manufacturers of lead-acid batteries has indicated that all the scrap wastes from the process; i.e., grids, paste mix, reject plates, etc., are recovered and sent to a lead smelter for processing as secondary lead and reuse. Hence, with regard to the raw wastes mentioned above, all of the solids, dusts, and pastes from (a), (b), (d), (e), and some of suspended lead in (c), (f), and (g) are recovered and recycled to a lead smelter in the course of normal operation.

The amount of lead solid wastes produced from treatment of waterwaste streams is difficult to assess at the present time due to the lack of EPA guidelines or pretreatment standards for waterwaste from a lead acid plant. In the absence of guidelines for this industry, a modeled treatment system was developed based upon current practices in the industry. The results of this modeled treatment yield quantities of lead in the treated effluent and the amount of lead removed which can be assumed would be the maximum amount to be destined for land disposal.

Thus, the waste stream destined for land disposal for the typical lead-acid plant is a wastewater treatment sludge which can be produced either by caustic soda neutralization or by lime neutralization. If caustic neutralization is used, the sludge will come from the filter unit in the wastewater treatment operation. If the wastewater treatment uses flocculating agents to settle suspended solids, these will be present in the sludge and may cause the relcaim of the sludge by a lead smelter to be impossible. The caustic treatment sludge generally contains 20 to 65% by weight of water. The sludge from lime neutralization generally comes from the claifier underflow and is a much larger volume than the caustic neutralization sludge. It is estimated that 20% of the plants currently use or will use lime treatment in the next several years.

The lead-acid battery hazardous waste stream destined for land disposal is given below:

(a) Wastewater Treatment Sludge Using Caustic Soda Neutralization:

Pb Raw Waste Factor = 0.331 kg per 1000 kg batteries
Pb Effluent Factor = 0.01 kg per 1000 kg batteries
Pb Sludge Factor = 0.324 kg per 1000 kg batteries

Estimated Composition of Sludge:

$PbSO_4$ = 0.293 kg per 1000 kg batteries
$Pb(OH)_2$ = 0.140 kg per 1000 kg batteries
Water = 20 to 65%
Total Sludge (80% solids basis) = 0.541 kg per 1000 kg batteries
= 4456 kg per year for the typical plant

OR

(b) Wastewater Treatment Sludge Using Lime Neutralization:

$CaSO_4$ Factor = 735 kg (dry basis) per 1000 kg batteries
= 2101 kg sludge basis (35% solids) per 1000 kg batteries

Sludge Composition: = 17,298 metric tons per year for the typical plant

$CaSO_4$ = 2101 kg per 1000 batteries (35% solids basis)
$Pb(OH)_2$ = 0.140 kg per 1000 kg batteries
$PbSO_4$ = 0.293 kg per 1000 kg batteries
Pb = 150 mg per liter (in total sludge)

The composition and quantities of sludges summarized above are based upon the lead-acid typical plant.

Tables 21, 22, and 23 show the quantities of hazardous wastes destined for land disposal from the lead-acid storage battery industry for three time periods--1972, 1977, and 1983. Each table shows the quantity of active hazardous material, on a water-free basis, in the waste stream together with the total amount of the waste stream based upon the waste factors derived in a previous section.

Table 21. 3691, Amount of Lead-Acid Battery Hazardous Wastes Destined for Land Disposal (1972)

REGION/STATE	Pb (Dry Basis) in Caustic Treatment Sludges kg	Caustic Treatment Sludge (Wet Basis) kg	Pb (Dry Basis) in Lime Treatment Sludges kg	Lime Treatment Sludge (Wet Basis) kkg
IV Alabama	0	0	0	0
X Alaska	0	0	0	0
IX Arizona	0	0	0	0
VI Arkansas	0	0	0	0
IX California	8,462	24,177	178	1,245
VIII Colorado	0	0	0	0
I Connecticut	620	1,771	13.1	91.3
III Delaware	5,500	15,714	60.1	420
IV Florida	690	1,971	15.3	107
IV Georgia	0	0	0	0
IX Hawaii	0	0	0	0
X Idaho	0	0	0	0
V Illinois	2,800	8,000	147	1,030
V Indiana	3,000	8,571	215	1,500
VII Iowa	0	0	0	0
VII Kansas	0	0	0	0
IV Kentucky	0	0	0	0
VI Louisiana	0	0	0	0
I Maine	0	0	0	0
III Maryland	0	0	0	0
I Massachusetts	0	0	0	0
V Michigan	1,550	4,429	33.1	199
V Minnesota	660	1,886	14.2	102
IV Mississippi	0	0	0	0
VII Missouri	0	0	0	0
VIII Montana	0	0	0	0
VII Nebraska	0	0	0	0
IX Nevada	0	0	0	0
I New Hampshire	0	0	0	0
II New Jersey	3,250	9,286	174	1,218
VI New Mexico	0	0	0	0
II New York	156	446	0	0
IV North Carolina	0	0	0	0
VIII North Dakota	0	0	0	0
V Ohio	800	2,286	20.1	141
VI Oklahoma	0	0	0	0
X Oregon	0	0	60.5	423
III Pennsylvania	0	0	270	1,886
I Rhode Island	0	0	0	0
IV South Carolina	0	0	0	0
VIII South Dakota	0	0	0	0
IV Tennessee	0	0	0	0
VI Texas	3,590	10,257	94.4	660
VIII Utah	0	0	0	0
I Vermont	0	0	0	0
III Virginia	0	0	0	0
X WAshington	0	0	0	0
III West Virginia	0	0	0	0
V Wisconsin	702	2,006	14.8	104
VIII Wyoming	0	0	0	0
TOTAL	31,780	90,800	1,309.6	9,126.3
Region I	620	1,771	13.1	91.3
II	3,406	9,732	174	1,218
III	5,500	15,714	330.1	2,306
IV	690	1,971	15.3	107
V	9,512	27,178	444.2	3,076
VI	3,590	10,257	94.4	660
VII	0	0	0	0
VIII	0	0	0	0
IX	8,462	24,177	178	1,245
X	0	0	60.5	423

Table 22. 3691 Amount of Lead-Acid Battery Hazardous Wastes Destined for Land Disposal (1977)

REGION/STATE	Pb (Dry Basis) in Caustic Treatment Sludges kg	Caustic Treatment Sludge (Wet Basis) kg	Pb (Dry Basis) in Lime Treatment Sludges kg	Lime Treatment Sludge (Wet Basis) kkg
IV Alabama	3,482	0	0	0
X Alaska	172	0	0	0
IX Arizona	171	0	0	0
VI Arkansas	559	0	0	0
IX California	48,350	16,923	16,923	22,152
VIII Colorado	452	0	0	0
I Connecticut	3,103	1,241	1,241	1,625
III Delaware	5,713	5,713	5,713	7,479
IV Florida	7,281	1,456	1,456	1,906
IV Georgia	14,832	0	0	0
IX Hawaii	0	0	0	0
X Idaho	0	0	0	0
V Illinois	21,535	13,998	13,998	18,323
V Indiana	31,362	20,385	20,385	26,685
VII Iowa	1,765	0	0	0
VII Kansas	11,247	0	0	0
IV Kentucky	10,200	0	0	0
VI Louisiana	731	0	0	0
I Maine	0	0	0	0
III Maryland	172	0	0	0
I Massachusetts	2,971	0	0	0
V Michigan	15,742	3,148	3,148	3,533
V Minnesota	6,737	1,347	1,347	1,816
IV Mississippi	3,317	0	0	0
VII Missouri	4,220	0	0	0
VIII Montana	0	0	0	0
VII Nebraska	1,207	0	0	0
IX Nevada	0	0	0	0
I New Hampshire	0	0	0	0
II New Jersey	20,687	16,550	16,550	21,664
VI New Mexico	172	0	0	0
II New York	1,248	187	187	245
IV North Carolina	4,647	0	0	0
VIII North Dakota	0	0	0	0
V Ohio	3,834	1,912	1,912	2,509
VI Oklahoma	2,930	0	0	0
X Oregon	8,221	5,755	5,755	7,533
III Pennsylvania	42,733	25,640	25,640	33,563
I Rhode Island	559	0	0	0
IV South Carolina	9,654	0	0	0
VIII South Dakota	0	0	0	0
IV Tennessee	6,206	0	0	0
VI Texas	29,914	8,974	8,974	11,748
VIII Utah	0	0	0	0
I Vermont	5,869	5,869	5,869	0
III Virginia	5,516	0	0	0
X WAshington	517	0	0	0
III West Virginia	0	0	0	0
V Wisconsin	7,041	1,408	1,408	1,844
VIII Wyoming	0	0	0	0
TOTAL	345,069	130,506	130,506	162,625
Region I	12,502	7,110	7,110	1,625
II	21,935	16,737	16,737	21,909
III	54,134	31,353	31,353	41,042
IV	59,619	1,456	1,456	1,906
V	86,251	42,198	42,198	54,710
VI	34,306	8,974	8,974	11,748
VII	18,439	0	0	0
VIII	452	0	0	0
IX	48,521	16,923	16,923	22,152
X	8,910	5,755	5,755	7,533

Table 23. 3691 Amount of Lead-Acid Battery Hazardous Wastes Destined for Land Disposal (1983)

REGION/STATE	Pb (Dry Basis) in Caustic Treatment Sludges kg	Caustic Treatment Sludge (Wet Basis) kg	Pb (Dry Basis) in Lime Treatment Sludges kg	Lime Treatment Sludge (Wet Basis) kkg
IV Alabama	4,444			
X Alaska	220			
IX Arizona	219			
VI Arkansas	713			
IX California	61,708	21,599	16,923	28,272
VIII Colorado	577			
I Connecticut	3,960	1,583	1,241	2,074
III Delaware	7,291	7,291	5,713	9,545
IV Florida	9,293	1,858	1,456	2,433
IV Georgia	18,930			
IX Hawaii				
X Idaho				
V Illinois	27,485	17,865	13,998	23,385
V Indiana	40,026	26,016	20,385	34,058
VII Iowa	2,253			
VII Kansas	14,354			
IV Kentucky	13,018			
VI Louisiana	933			
I Maine				
III Maryland	219			
I Massachusetts	3,792			
V Michigan	20,091	4,018	3,148	4,509
V Minnesota	8,598	1,719	1,347	2,318
IV Mississippi	4,233			
VII Missouri	5,386			
VIII Montana				
VII Nebraska	1,540			
IX Nevada				
I New Hampshire				
II New Jersey	26,402	21,122	16,550	27,649
VI New Mexico	219			
II New York	1,593	239	187	313
IV North Carolina	5,930			
VIII North Dakota				
V Ohio	4,893	2,440	1,912	3,202
VI Oklahoma	3,740			
X Oregon	10,492	7,345	5,755	9,614
III Pennsylvania	55,539	32,723	25,640	42,835
I Rhode Island	713			
IV South Carolina	12,321			
VIII South Dakota				
IV Tennessee	7,921			
VI Texas	38,179	11,453	8,974	14,994
VIII Utah				
I Vermont	7,490	7,490	5,869	
III Virginia	7,040			
X WAshington	660			
III West Virginia				
V Wisconsin	8,986	1,797	1,408	2,353
VIII Wyoming				
TOTAL	441,401	166,558	130,506	207,554
Region I	15,955	9,073	7,110	2,074
II	27,995	21,361	16,737	27,962
III	70,089	40,014	31,353	52,380
IV	76,090	1,858	1,456	2,433
V	110,079	53,855	42,198	69,825
VI	43,784	11,453	8,974	14,994
VII	23,533			
VIII	577			
IX	61,927	21,599	16,923	28,272
X	11,372	7,345	5,755	9,614

The projections of hazardous wastes for 1977 and 1983 include the expected impact of EPA wastewater pre-treatment standards for large plants discharging to municipal sewage systems. For example, in the 1977 projection (Table 22), the first column represents the maximum dry lead metal which would be removed due to pre-treatment. The figures in the second column represent the Contractor's estimate of the amount of lead metal which will be destined for land disposal contained in the lead metal sludges and the calcium sulfate sludges shown in the next two columns. This data was based upon existing and future wastewater regulations in water quality sensitive states. The units for the active hazardous compound lead, and the lead sludges are kilograms (kg), while the units for the calcium sulfate sludge is metric tons (kkg).

5.4.1.2 Nickel Cadmium Battery

The potentially hazardous wastes from the production of this type of battery include the following:

(a) Wastewaters containing cadmium and nickel salts together with potassium hydroxide. The source of this waste is the washing steps. This waste is estimated to amount to 3.24 kg nickel nitrate and 7.96 kg cadmium nitrate per 1000 kg of product in the untreated wastewater;

(b) Solid wastes recovered from treatment of wastewaters. These are estimated to contain cadmium hydroxide (5.339 kg) and nickel hydroxide (1.660 kg) per 1000 kg of product; and

(c) Rejected batteries from the test and package step. They contain 1.47 kg nickel and 5.20 kg cadmium per 1000 kg of product.

Industry sources have indicated that the two waste streams shown above are not in most cases destined for land disposal. In none of the plants surveyed were both of these waste streams going to land disposal. Of the nine plants currently producing nickel cadmium batteries, three plants have no wastewater treatment sludge due to their production processes, two plants are using on-site impoundment areas and the remaining plants are selling the sludges to scrap reclaimers. Only two plants were found which use land disposal of scrap batteries, the others sell the scrap to reprocessors.

Tables 24, 25, and 26 show the quantities of hazardous wastes destined for land disposal from the nickel cadmium storage battery industry for three time periods--1973, 1977, and 1983. Each table shows the quantity of active hazardous material on a water-free basis in the waste stream together with the total amount of the waste stream based upon the waste factors derived in a previous section, and knowledge of the industry disposal practices.

Table 24. 3691 Amount of Nickel Cadmium Battery Hazardous Wastes Destined for Land Disposal (1973)

REGION/STATE	Scrap Cells			Sludge		
	Nickel Metal (dry basis) kg	Cadmium Metal (dry basis) kg	Total Scrap waste stream kg	Cadmium Hydroxide Sludge (dry basis) kg	Nickel Hydroxide Sludge (dry basis) kg	Total Sludge Waste Stream kg
IV Alabama	0	0	0	0	0	0
X Alaska	0	0	0	0	0	0
IX Arizona	0	0	0	0	0	0
VI Arkansas	0	0	0	0	0	0
IX California	0	0	0	0	0	0
VIII Colorado	0	0	0	0	0	0
I Connecticut	0	0	0	0	0	0
III Delaware	0	0	0	0	0	0
IV Florida	0	0	0	8,279	2,574	31,009
IV Georgia	0	0	0	0	0	0
IX Hawaii	0	0	0	0	0	0
X Idaho	0	0	0	0	0	0
V Illinois	0	0	0	0	0	0
V Indiana	0	0	0	0	0	0
VII Iowa	35	125	220	0	0	0
VII Kansas	0	0	0	0	0	0
IV Kentucky	0	0	0	0	0	0
VI Louisiana	0	0	0	0	0	0
I Maine	0	0	0	0	0	0
III Maryland	0	0	0	0	0	0
I Massachusetts	0	0	0	0	0	0
V Michigan	0	0	0	0	0	0
V Minnesota	0	0	0	0	0	0
IV Mississippi	0	0	0	0	0	0
VII Missouri	0	0	0	0	0	0
VIII Montana	0	0	0	0	0	0
VII Nebraska	0	0	0	0	0	0
IX Nevada	0	0	0	0	0	0
I New Hampshire	0	0	0	0	0	0
II New Jersey	0	0	0	0	0	0
VI New Mexico	0	0	0	0	0	0
II New York	0	0	0	0	0	0
IV North Carolina	0	0	0	0	0	0
VIII North Dakota	0	0	0	0	0	0
V Ohio	1,187	1,905	4,397	0	0	0
VI Oklahoma	0	0	0	0	0	0
X Oregon	0	0	0	0	0	0
III Pennsylvania	0	0	0	0	0	0
I Rhode Island	0	0	0	0	0	0
IV South Carolina	0	0	0	0	0	0
VIII South Dakota	0	0	0	0	0	0
IV Tennessee	0	0	0	0	0	0
VI Texas	0	0	0	0	0	0
VIII Utah	0	0	0	0	0	0
I Vermont	0	0	0	0	0	0
III Virginia	0	0	0	0	0	0
X WAshington	0	0	0	0	0	0
III West Virginia	0	0	0	0	0	0
V Wisconsin	0	0	0	0	0	0
VIII Wyoming	0	0	0	0	0	0
TOTAL	1,222	2,030	4,617	8,279	2,574	31,009
Region I	0	0	0	0	0	0
II	0	0	0	0	0	0
III	0	0	0	0	0	0
IV	0	0	0	8,279	2,574	31,009
V	1,187	1,905	4,397	0	0	0
VI	0	0	0	0	0	0
VII	35	125	220	0	0	0
VIII	0	0	0	0	0	0
IX	0	0	0	0	0	0
X	0	0	0	0	0	0

Table 25. Amount of Nickel Cadmium Battery Hazardous Wastes Destined for Land Disposal (1977)

	Scrap Cells			Sludge		
REGION/STATE	Nickel Metal (dry basis) kg	Cadmium Metal (dry basis) kg	Total Scrap waste stream kg	Cadmium Hydroxide Sludge (dry basis) kg	Nickel Hydroxide Sludge (dry basis) kg	Total Sludge Waste Stream kg
IV Alabama	0	0	0	0	0	0
X Alaska	0	0	0	0	0	0
IX Arizona	0	0	0	0	0	0
VI Arkansas	0	0	0	0	0	0
IX California	0	0	0	0	0	0
VIII Colorado	0	0	0	0	0	0
I Connecticut	0	0	0	0	0	0
III Delaware	0	0	0	0	0	0
IV Florida	0	0	0	9,935	3,089	37,211
IV Georgia	0	0	0	0	0	0
IX Hawaii	0	0	0	0	0	0
X Idaho	0	0	0	0	0	0
V Illinois	0	0	0	0	0	0
V Indiana	0	0	0	0	0	0
VII Iowa	0	0	0	0	0	0
VII Kansas	0	0	0	0	0	0
IV Kentucky	0	0	0	0	0	0
VI Louisiana	0	0	0	0	0	0
I Maine	0	0	0	0	0	0
III Maryland	0	0	0	0	0	0
I Massachusetts	0	0	0	0	0	0
V Michigan	0	0	0	0	0	0
V Minnesota	0	0	0	0	0	0
IV Mississippi	0	0	0	0	0	0
VII Missouri	0	0	0	0	0	0
VIII Montana	0	0	0	0	0	0
VII Nebraska	0	0	0	0	0	0
IX Nevada	0	0	0	0	0	0
I New Hampshire	0	0	0	0	0	0
II New Jersey	0	0	0	0	0	0
VI New Mexico	0	0	0	0	0	0
II New York	0	0	0	0	0	0
IV North Carolina	0	0	0	0	0	0
VIII North Dakota	0	0	0	0	0	0
V Ohio	1,424	2,286	5,276	1,956	608	7,326
VI Oklahoma	0	0	0	0	0	0
X Oregon	0	0	0	0	0	0
III Pennsylvania	0	0	0	0	0	0
I Rhode Island	0	0	0	0	0	0
IV South Carolina	0	0	0	0	0	0
VIII South Dakota	0	0	0	0	0	0
IV Tennessee	0	0	0	0	0	0
VI Texas	0	0	0	0	0	0
VIII Utah	0	0	0	0	0	0
I Vermont	0	0	0	0	0	0
III Virginia	0	0	0	0	0	0
X WAshington	0	0	0	0	0	0
III West Virginia	0	0	0	0	0	0
V Wisconsin	0	0	0	0	0	0
VIII Wyoming	0	0	0	0	0	0
TOTAL	1,424	2,286	5,276	11,891	3,697	44,537
Region I	0	0	0	0	0	0
II	0	0	0	0	0	0
III	0	0	0	0	0	0
IV	0	0	0	9,935	3,089	37,211
V	1,424	2,286	5,276	1,956	608	7,326
VI	0	0	0	0	0	0
VII	0	0	0	0	0	0
VIII	0	0	0	0	0	0
IX	0	0	0	0	0	0
X	0	0	0	0	0	0

Table 26. 3691 Amount of Nickel Cadmium Battery Hazardous Wastes Destined for Land Disposal (1983)

REGION/STATE		Scrap Cells			Sludge		
		Nickel Metal (dry basis) kg	Cadmium Metal (dry basis) kg	Total Scrap waste stream kg	Cadmium Hydroxide Sludge (dry basis) kg	Nickel Hydroxide Sludge (dry basis) kg	Total Sludge Waste Stream kg
IV	Alabama	0	0	0	0	0	0
X	Alaska	0	0	0	0	0	0
IX	Arizona	0	0	0	0	0	0
VI	Arkansas	0	0	0	0	0	0
IX	California	0	0	0	0	0	0
VIII	Colorado	0	0	0	0	0	0
I	Connecticut	0	0	0	0	0	0
III	Delaware	0	0	0	0	0	0
IV	Florida	0	0	0	11,922	3,707	44,653
IV	Georgia	0	0	0	0	0	0
IX	Hawaii	0	0	0	0	0	0
X	Idaho	0	0	0	0	0	0
V	Illinois	0	0	0	0	0	0
V	Indiana	0	0	0	0	0	0
VII	Iowa	0	0	0	0	0	0
VII	Kansas	0	0	0	0	0	0
IV	Kentucky	0	0	0	0	0	0
VI	Louisiana	0	0	0	0	0	0
I	Maine	0	0	0	0	0	0
III	Maryland	0	0	0	0	0	0
I	Massachusetts	0	0	0	0	0	0
V	Michigan	0	0	0	0	0	0
V	Minnesota	0	0	0	0	0	0
IV	Mississippi	0	0	0	0	0	0
VII	Missouri	0	0	0	0	0	0
VIII	Montana	0	0	0	0	0	0
VII	Nebraska	0	0	0	0	0	0
IX	Nevada	0	0	0	0	0	0
I	New Hampshire	0	0	0	0	0	0
II	New Jersey	0	0	0	0	0	0
VI	New Mexico	0	0	0	0	0	0
II	New York	0	0	0	0	0	0
IV	North Carolina	0	0	0	0	0	0
VIII	North Dakota	0	0	0	0	0	0
V	Ohio	0	0	0	0	0	0
VI	Oklahoma	0	0	0	0	0	0
X	Oregon	0	0	0	0	0	0
III	Pennsylvania	0	0	0	0	0	0
I	Rhode Island	0	0	0	0	0	0
IV	South Carolina	0	0	0	0	0	0
VIII	South Dakota	0	0	0	0	0	0
IV	Tennessee	0	0	0	0	0	0
VI	Texas	0	0	0	0	0	0
VIII	Utah	0	0	0	0	0	0
I	Vermont	0	0	0	0	0	0
III	Virginia	0	0	0	0	0	0
X	WAshington	0	0	0	0	0	0
III	West Virginia	0	0	0	0	0	0
V	Wisconsin	0	0	0	0	0	0
VIII	Wyoming	0	0	0	0	0	0
TOTAL		0	0	0	11,922	3,707	44,653
Region I		0	0	0	0	0	0
II		0	0	0	0	0	0
III		0	0	0	0	0	0
IV		0	0	0	11,922	3,707	44,653
V		0	0	0	0	0	0
VI		0	0	0	0	0	0
VII		0	0	0	0	0	0
VIII		0	0	0	0	0	0
IX		0	0	0	0	0	0
X		0	0	0	0	0	0

5.4.1.3 Other Storage Batteries

5.4.1.3.1 Cadmium-Silver Oxide Battery

The wastes involved in the production of this type of battery include the following:

(a) Wastewaters containing cadmium and silver salts together with potassium hydroxide, the source of this waste is the washing of the plates and the waste amounts to 3.01 kg of silver nitrate and 7.96 kg of cadmium nitrate per 1000 kg of batteries produced (dry basis);

(b) Sludge wastes recovered from treatment of the wastewaters, the sludges typically contain 5.34 kg of cadmium hydroxide and 2.24 kg of silver oxide (dry basis) per 1000 kg of batteries produced; and

(c) Rejected batteries from quality control testing, these contain approximately 2.70 kg silver per 1000 kg batteries and 5.20 kg cadmium per 1000 kg batteries.

The actual amounts of hazardous waste destined for land disposal from the production of this cell could not be determined from industry sources, but the reclamation of valuable materials such as silver and cadmium would be an economic necessity for the manufacturers of this battery type. On the basis of economic considerations and, information from industry sources, there are no potentially hazardous wastes destined for land disposal from this process.

5.4.1.3.2 Zinc-Silver Oxide Secondary Battery

This battery is a specialty item produced primarily for military uses in limited production quantities.

The wastes from the production of this cell could not be determined from industry sources, but there appear to be no hazardous water-borne wastes from this process, only potassium hydroxide. The potentially hazardous waste products from rejected cells would be zinc, mercury, and silver. Since the scrap cells contain silver, they are sold to scrap reclaimers for their silver content. On the basis of economic considerations and information from industry sources, there are no potentially hazardous wastes destined for land disposal from this process.

Tables 27, 28, and 29 show the quantities of hazardous wastes from the production of cadmium-silver and zinc-silver cells categorized in the "other" storage batteries industry for three time periods--1973, 1977, and 1983. Each table shows the

Table 27. 3691 Amount of Other Storage Battery Hazardous Wastes* (1973)

REGION/STATE		Zinc Metal kg	Cadmium Metal kg	Silver Metal kg	Mercury Metal kg	Water Treatment Sludges containing silver, cadmium & mercury kg	Total Waste Stream kg
IV	Alabama						
X	Alaska						
IX	Arizona						
VI	Arkansas						
IX	California	0.21	0	1.2	0.013	0	1.7
VIII	Colorado	1.7	0	7.1	0.10	0	12.1
I	Connecticut						
III	Delaware						
IV	Florida	0	0	0	0	466.1	1,332
IV	Georgia						
IX	Hawaii						
X	Idaho						
V	Illinois						
V	Indiana						
VII	Iowa						
VII	Kansas						
IV	Kentucky						
VI	Louisiana						
I	Maine						
III	Maryland						
I	Massachusetts						
V	Michigan						
V	Minnesota						
IV	Mississippi						
VII	Missouri	0.38	10.6	30.8	0.02	161.2	461.5
VIII	Montana						
VII	Nebraska						
IX	Nevada						
I	New Hampshire						
II	New Jersey						
VI	New Mexico						
II	New York						
IV	North Carolina	0.93	26	75.5	0.05	395	1,130
VIII	North Dakota						
V	Ohio						
VI	Oklahoma						
X	Oregon	0.22	0	1.2	0.012	0	1.8
III	Pennsylvania						
I	Rhode Island	8.3	1.2	0	0	0	12.7
IV	South Carolina						
VIII	South Dakota						
IV	Tennessee						
VI	Texas						
VIII	Utah						
I	Vermont						
III	Virginia						
X	WAshington						
III	West Virginia						
V	Wisconsin						
VIII	Wyoming						
TOTAL		11.74	37.8	115.8	0.195	1,022.3	2,951.8
Region I		8.3	1.2	0	0	0	12.7
II		0	0	0	0	0	0
III		0	0	0	0	0	0
IV		0.93	26	75.5	0.05	861.1	2,462
V		0	0	0	0	0	0
VI		0	0	0	0	0	0
VII		0.38	10.6	30.8	0.02	161.2	461.5
VIII		1.7	0	7.1	0.10	0	12.1
IX		0.21	0	1.2	0.013	0	1.7
X		0.22	0	1.2	0.012	0	1.8

*Not destined for land disposal (reclaimed).

Table 28. 3691 Amount of Other Storage Battery Hazardous Wastes* (1977)

REGION / STATE	Zinc Metal kg	Cadmium Metal kg	Silver Metal kg	Mercury Metal kg	Water Treatment Sludges containing silver and cadmium kg	Total Waste Stream kg
IV Alabama						
X Alaska						
IX Arizona						
VI Arkansas						
IX California	0.24	0	1.4	0.015	0	2.0
VIII Colorado	2.0	0	8.2	0.12	0	14
I Connecticut						
III Delaware						
IV Florida	0	0	0	0	540.7	1,545
IV Georgia						
IX Hawaii						
X Idaho						
V Illinois						
V Indiana						
VII Iowa						
VII Kansas						
IV Kentucky						
VI Louisiana						
I Maine						
III Maryland						
I Massachusetts						
V Michigan						
V Minnesota						
IV Mississippi						
VII Missouri	0.44	12.3	35.7	0.02	187	535.3
VIII Montana						
VII Nebraska						
IX Nevada						
I New Hampshire						
II New Jersey						
VI New Mexico						
II New York						
IV North Carolina	1.08	30.2	87.6	0.06	458	1,311
VIII North Dakota						
V Ohio						
VI Oklahoma						
X Oregon	0.26	0	1.4	0.02	0	2.1
III Pennsylvania						
I Rhode Island	9.6	1.4	0	0	0	14.7
IV South Carolina						
VIII South Dakota						
IV Tennessee						
VI Texas						
VIII Utah						
I Vermont						
III Virginia						
X WAshington						
III West Virginia						
V Wisconsin						
VIII Wyoming						
TOTAL	13.62	43.9	134.3	0.235	1,185.7	3,424.1
Region I	9.6	1.4	0	0	0	14.7
II	0	0	0	0	0	0
III	0	0	0	0	0	0
IV	1.08	30.2	87.6	0.06	998.7	2,856
V	0	0	0	0	0	0
VI	0	0	0	0	0	0
VII	0.44	12.3	35.7	0.02	187	535.3
VIII	2.0	0	8.2	0.12	0	14
IX	0.24	0	1.4	0.015	0	2.0
X	0.26	0	1.4	0.02	0	2.1

*Not destined for land disposal (reclaimed).

Table 29. 3691 Amount of Other Storage Battery Hazardous Wastes* (1983)

REGION/STATE		Zinc Metal kg	Cadmium Metal kg	Silver Metal. kg	Mercury Metal kg	Water Treatment Sludges containing silver and cadmium kg	Total Waste Stream kg
IV	Alabama						
X	Alaska						
IX	Arizona						
VI	Arkansas						
IX	California	0.25	0	1.4	0.016	0	2.1
VIII	Colorado	2.1	0	8.6	0.12	0	14.6
I	Connecticut						
III	Delaware						
IV	Florida	0	0	0	0	564	1,612
IV	Georgia						
IX	Hawaii						
X	Idaho						
V	Illinois						
V	Indiana						
VII	Iowa						
VII	Kansas						
IV	Kentucky						
VI	Louisiana						
I	Maine						
III	Maryland						
I	Massachusetts						
V	Michigan						
V	Minnesota						
IV	Mississippi						
VII	Missouri	0.46	12.8	37.3	0.04	195.1	558
VIII	Montana						
VII	Nebraska						
IX	Nevada						
I	New Hampshire						
II	New Jersey						
VI	New Mexico						
II	New York						
IV	North Carolina	1.13	31.5	91.4	0.06	478	1,167
VIII	North Dakota						
V	Ohio						
VI	Oklahoma						
X	Oregon	0.27	0	1.45	0.015	0	2.2
III	Pennsylvania						
I	Rhode Island	10	1.5	0	0	0	15.4
IV	South Carolina						
VIII	South Dakota						
IV	Tennessee						
VI	Texas						
VIII	Utah						
I	Vermont						
III	Virginia						
X	WAshington						
III	West Virginia						
V	Wisconsin						
VIII	Wyoming						
TOTAL		14.21	45.8	140.15	0.251	1,237.1	3,371.3
Region I		10	1.5	0	0	0	15.4
II		0	0	0	0	0	0
III		0	0	0	0	0	0
IV		1.13	31.5	91.4	0.06	1,042	2,779
V		0	0	0	0	0	0
VI		0	0	0	0	0	0
VII		0.46	12.8	37.3	0.04	195.1	558
VIII		2.1	0	8.6	0.12	0	14.6
IX		0.25	0	1.4	0.016	0	2.1
X		0.27	0	1.45	0.015	0	2.2

*Not destined for land disposal (reclaimed).

quantity of active hazardous material, on a water free basis, in the waste stream together with the total amount of the waste stream based upon the waste factors derived in a previous section. The contractor has estimated on the basis of the best information available that these wastes are not destined for land disposal.

5.4.2 SIC 3692, Primary Batteries Waste Streams Summary

5.4.2.1 Carbon-Zinc Battery

The wastes from the production of carbon-zinc batteries consist of mercury, zinc, zinc chloride, manganese dioxide, cadmium, and lead. These wastes are contained in rejected batteries. The amount of wastes from rejected batteries include 0.0073 kg mercury, 3.812 kg zinc, 0.248 kg zinc chloride, 6.147 kg manganese dioxide, 0.00027 cadmium, and 0.00031 kg lead per 1000 kg of batteries produced.

Tables 30, 31, and 32 show the quantities of hazardous wastes destined for land disposal from the carbon-zinc primary battery industry for three time periods--1973, 1977, and 1983. Each table shows the quantity of active hazardous material, on a water free basis, in the waste stream together with the total amount of the waste stream based upon the waste factors derived in a previous section.

5.4.2.2 Alkaline-Manganese Battery

The hazardous wastes from the production of alkaline-manganese batteries consist of zinc and mercury. The wastes associated with alkaline cell production include mercury at the rate of 0.076 kg per 1000 kg product; zinc at 1.622 kg per 1000 kg product; and manganese dioxide at 2.744 kg per 1000 kg product. The total waste stream consists of rejected batteries.

Tables 33, 34, and 35 show the quantities of hazardous wastes destined for land disposal from the alkaline-manganese primary battery industry for three time periods--1973, 1977, and 1983. Each table shows the quantity of active hazardous material, on a water free basis, in the waste stream together with the total amount of the waste stream based upon the waste factors derived in a previous section.

5.4.2.3 Mercury Ruben Battery

The wastes from the Ruben cell process are in the form of rejected batteries. Greater than 95% of the rejected batteries are reclaimed, but some are sent to landfills. The wastes from rejected batteries are 1.61 kg mercuric oxide, 0.39 kg mercury and 5.60 kg zinc per 1000 kg product. Wastes from the reclaim furnace consist of unreacted residue which is typically deposited in a landfill. The residue is estimated to contain 0.0001 kg mercury, 5.60 kg zinc and 2.40 kg of iron per 1000 kg of product.

Table 30. 3692 Amount of Carbon-Zinc Battery Hazardous Wastes Destined for Land Disposal (1973)

REGION/STATE		Zinc Metal kg	Mercury Metal kg	Lead Metal kg	Cadmium Metal kg	Zinc Chloride kg	Total Waste Stream kg
IV	Alabama						
X	Alaska						
IX	Arizona						
VI	Arkansas						
IX	California						
VIII	Colorado						
I	Connecticut	86.3	0.2	0.01	0.01	4.5	227.0
III	Delaware						
IV	Florida						
IV	Georgia						
IX	Hawaii						
X	Idaho						
V	Illinois	10,814	20.9	0.9	0.9	703.7	28,375
V	Indiana						
VII	Iowa	11,423	21.8	0.9	0.9	744.6	29,964
VII	Kansas						
IV	Kentucky						
VI	Louisiana						
I	Maine						
III	Maryland						
I	Massachusetts						
V	Michigan						
V	Minnesota						
IV	Mississippi						
VII	Missouri						
VIII	Montana						
VII	Nebraska						
IX	Nevada						
I	New Hampshire						
II	New Jersey	10,814	20.9	0.9	0.9	703.7	28,375
VI	New Mexico						
II	New York						
IV	North Carolina	114,440	79.3	9.1	9.1	7,446	300,208
VIII	North Dakota						
V	Ohio	131,279	251.5	10.4	10.4	8,540	344,388
VI	Oklahoma						
X	Oregon						
III	Pennsylvania	8,653	16.3	0.5	0.5	563.0	22,700
I	Rhode Island						
IV	South Carolina	867.1	1.8	0.1	0.1	54.5	2,270
VIII	South Dakota						
IV	Tennessee						
VI	Texas						
VIII	Utah						
I	Vermont	2,719	5.0	0.2	0.2	177.1	7,137
III	Virginia						
X	WAshington						
III	West Virginia						
V	Wisconsin	74,547	142.6	5.9	5.9	4,849	195,560
VIII	Wyoming						
TOTAL		365,642	560.3	28.9	28.9	23,786	959,202
Region	I	2,806	5.2	0.2	0.2	181.6	7,364
	II	10,814	20.9	0.9	0.9	703.7	28,375
	III	8,653	16.3	0.5	0.5	563.0	22,700
	IV	115,307	81.1	9.2	9.2	7,500	332,478
	V	216,640	415.0	17.2	17.2	14,093	568,322
	VI	0	0	0	0	0	0
	VII	11,423	21.8	0.9	0.9	744.6	29,964
	VIII	0	0	0	0	0	0
	IX	0	0	0	0	0	0
	X	0	0	0	0	0	0

Table 31. 3692 Amount of Carbon-Zinc Battery Hazardous Wastes Destined for Land Disposal (1977)

REGION/STATE	Zinc Metal kg	Mercury Metal kg	Lead Metal kg	Cadmium Metal kg	Zinc Chloride kg	Total Waste Stream kg
IV Alabama						
X Alaska						
IX Arizona						
VI Arkansas						
IX California						
VIII Colorado						
I Connecticut	89.8	0.2	0.01	0.01	5.5	255.4
III Delaware						
IV Florida						
IV Georgia						
IX Hawaii						
X Idaho						
V Illinois	11,253	25.4	0.9	0.9	855.3	33,170
V Indiana						
VII Iowa	11,887	25.5	0.9	0.9	905.1	35,028
VII Kansas						
IV Kentucky						
VI Louisiana						
I Maine						
III Maryland						
I Massachusetts						
V Michigan						
V Minnesota						
IV Mississippi						
VII Missouri						
VIII Montana						
VII Nebraska						
IX Nevada						
I New Hampshire						
II New Jersey	11,253	25.4	0.9	0.9	855.3	33,170
VI New Mexico						
II New York						
IV North Carolina	119,086	85.6	9.5	9.5	9,051	350,943
VIII North Dakota						
V Ohio	136,609	305.7	10.8	10.8	10,380	402,587
VI Oklahoma						
X Oregon						
III Pennsylvania	9,004	19.8	0.5	0.5	684.3	26,536
I Rhode Island						
IV South Carolina	902.3	2.2	0.1	0.1	66.2	2,653
VIII South Dakota						
IV Tennessee						
VI Texas						
VIII Utah						
I Vermont	2,829	6.1	0.2	0.2	215.3	8,343
III Virginia						
X WAshington						
III West Virginia						
V Wisconsin	77,574	173.3	6.1	6.1	5,894	228,610
VIII Wyoming						
TOTAL	380,487	670.2	29.9	29.9	28,912	1,121,305
Region I	2,919	6.3	0.2	0.2	220.8	8,608
II	11,253	25.4	0.9	0.9	855.3	33,170
III	9,004	19.8	0.5	0.5	684.3	26,536
IV	119,988	87.8	9.6	9.6	9,117	353,596
V	225,436	504.4	17.8	17.8	17,129	664,367
VI	0	0	0	0	0	0
VII	11,887	25.5	0.9	0.9	905.1	35,028
VIII	0	0	0	0	0	0
IX	0	0	0	0	0	0
X	0	0	0	0	0	0

Table 32. 3692 Amount of Carbon-Zinc Battery Hazardous Wastes Destined for Land Disposal (1983)

REGION/STATE	Zinc Metal kg	Mercury Metal kg	Lead Metal kg	Cadmium Metal kg	Zinc Chloride kg	Total Waste Stream kg
IV Alabama						
X Alaska						
IX Arizona						
VI Arkansas						
IX California						
VIII Colorado						
I Connecticut	86.3	0.2	0.01	0.01	4.5	226.9
III Delaware						
IV Florida						
IV Georgia						
IX Hawaii						
X Idaho						
V Illinois	10,810	20.9	0.9	0.9	703.4	28,363
V Indiana						
VII Iowa	11,418	21.8	0.9	0.9	744.3	29,952
VII Kansas						
IV Kentucky						
VI Louisiana						
I Maine						
III Maryland						
I Massachusetts						
V Michigan						
V Minnesota						
IV Mississippi						
VII Missouri						
VIII Montana						
VII Nebraska						
IX Nevada						
I New Hampshire						
II New Jersey	10,810	20.9	0.9	0.9	703.4	28,363
VI New Mexico						
II New York						
IV North Carolina	114,393	79.2	9.1	9.1	7,443	300,085
VIII North Dakota						
V Ohio	131,225	251.4	10.4	10.4	8,536	344,245
VI Oklahoma						
X Oregon						
III Pennsylvania	8,649	16.3	0.5	0.5	562.8	22,691
I Rhode Island						
IV South Carolina	866.7	1.8	0.1	0.1	54.5	2,269
VIII South Dakota						
IV Tennessee						
VI Texas						
VIII Utah						
I Vermont	2,718	5.0	0.2	0.2	177.0	7,134
III Virginia						
X Washington						
III West Virginia						
V Wisconsin	74,516	142.5	5.9	5.9	4,847	195,480
VIII Wyoming						
TOTAL	365,492	560	28.9	28.9	23,776	958,809
Region I	2,804	5.2	0.2	0.2	181.5	7,361
II	10,810	20.9	0.9	0.9	703.4	28,363
III	8,649	16.3	0.5	0.5	562.8	22,691
IV	115,260	81	9.2	9.2	7,497	302,354
V	216,551	414.8	17.2	17.2	14,086	568,088
VI	0	0	0	0	0	0
VII	11,418	21.8	0.9	0.9	744.3	29,952
VIII	0	0	0	0	0	0
IX	0	0	0	0	0	0
X	0	0	0	0	0	0

Table 33. 3692 Amount of Alkaline-Manganese Battery Hazardous Wastes Destined for Land Disposal (1973)

REGION/STATE	Zinc Metal kg	Mercury Metal kg	Total Waste Stream kg	
IV Alabama				
X Alaska				
IX Arizona				
VI Arkansas				
IX California				
VIII Colorado				
I Connecticut				
III Delaware				
IV Florida				
IV Georgia				
IX Hawaii				
X Idaho				
V Illinois				
V Indiana				
VII Iowa				
VII Kansas				
IV Kentucky				
VI Louisiana				
I Maine				
III Maryland				
I Massachusetts				
V Michigan				
V Minnesota				
IV Mississippi				
VII Missouri				
VIII Montana				
VII Nebraska				
IX Nevada				
I New Hampshire				
II New Jersey				
VI New Mexico				
II New York				
IV North Carolina	6,996	327.8	43,130	
VIII North Dakota				
V Ohio				
VI Oklahoma				
X Oregon				
III Pennsylvania	378.6	17.7	2,334	
I Rhode Island				
IV South Carolina				
VIII South Dakota				
IV Tennessee	2,869	134.4	17,688	
VI Texas				
VIII Utah				
I Vermont	213.4	10.0	1,317	
III Virginia				
X WAshington				
III West Virginia				
V Wisconsin	12,393	580.7	76,404	
VIII Wyoming				
TOTAL	22,850	1,071	140,873	
Region I	213.4	10.0	1,317	
II	0	0	0	
III	378.6	17.7	2,334	
IV	9,865	462.2	60,818	
V	12,393	580.7	76,404	
VI	0	0	0	
VII	0	0	0	
VIII	0	0	0	
IX	0	0	0	
X	0	0	0	

Table 34. 3692 Amount of Alkaline-Manganese Battery Hazardous Wastes Destined for Land Disposal (1977)

REGION/STATE		Zinc Metal kg	Mercury Metal kg	Total Waste Stream kg	
IV	Alabama				
X	Alaska				
IX	Arizona				
VI	Arkansas				
IX	California				
VIII	Colorado				
I	Connecticut				
III	Delaware				
IV	Florida				
IV	Georgia				
IX	Hawaii				
X	Idaho				
V	Illinois				
V	Indiana				
VII	Iowa				
VII	Kansas				
IV	Kentucky				
VI	Louisiana				
I	Maine				
III	Maryland				
I	Massachusetts				
V	Michigan				
V	Minnesota				
IV	Mississippi				
VII	Missouri				
VIII	Montana				
VII	Nebraska				
IX	Nevada				
I	New Hampshire				
II	New Jersey				
VI	New Mexico				
II	New York				
IV	North Carolina	8,178	383.2	50,419	
VIII	North Dakota				
V	Ohio				
VI	Oklahoma				
X	Oregon				
III	Pennsylvania	442.6	20.7	2,728	
I	Rhode Island				
IV	South Carolina				
VIII	South Dakota				
IV	Tennessee	3,354	157.1	20,677	
VI	Texas				
VIII	Utah				
I	Vermont	249.5	11.7	1,540	
III	Virginia				
X	WAshington				
III	West Virginia				
V	Wisconsin	14,487	678.8	89,316	
VIII	Wyoming				
TOTAL		26,711	1,252	164,680	
Region	I	249.5	11.7	1,540	
	II	0	0	0	
	III	442.6	20.7	2,728	
	IV	11,532	540.3	71,096	
	V	14,487	678.8	89,316	
	VI	0	0	0	
	VII	0	0	0	
	VIII	0	0	0	
	IX	0	0	0	
	X	0	0	0	

Table 35. 3692 Amount of Alkaline-Manganese Battery Hazardous Wastes Destined for Land Disposal (1983)

REGION/STATE	Zinc Metal kg	Mercury Metal kg	Total Waste Stream kg
IV Alabama			
X Alaska			
IX Arizona			
VI Arkansas			
IX California			
VIII Colorado			
I Connecticut			
III Delaware			
IV Florida			
IV Georgia			
IX Hawaii			
X Idaho			
V Illinois			
V Indiana			
VII Iowa			
VII Kansas			
IV Kentucky			
VI Louisiana			
I Maine			
III Maryland			
I Massachusetts			
V Michigan			
V Minnesota			
IV Mississippi			
VII Missouri			
VIII Montana			
VII Nebraska			
IX Nevada			
I New Hampshire			
II New Jersey			
VI New Mexico			
II New York			
IV North Carolina	8,507	398.6	52,446
VIII North Dakota			
V Ohio			
VI Oklahoma			
X Oregon			
III Pennsylvania	460.4	21.5	2,838
I Rhode Island			
IV South Carolina			
VIII South Dakota			
IV Tennessee	3,489	163.4	21,509
VI Texas			
VIII Utah			
I Vermont	259.5	12.2	1,601
III Virginia			
X WAshington			
III West Virginia			
V Wisconsin	15,070	706.1	21,163
VIII Wyoming			
TOTAL	27,786	1,302	99,557.0
Region I	259.5	12.2	1,601
II	0	0	0
III	460.4	21.5	2,838
IV	11,996	562.0	73,955
V	15,070	706.1	21,163
VI	0	0	0
VII	0	0	0
VIII	0	0	0
IX	0	0	0
X	0	0	0

Table 36, 37, and 38 show the quantities of hazardous wastes destined for land disposal from the mercury battery industry for three time periods--1973, 1977, and 1983. Each table shows the quantity of active hazardous material, on a water free basis, in the waste stream together with the total amount of the waste stream based upon the waste factors derived in a previous section. The future projections reflect environmental impact on future disposal of mercury cells and development of replacement batteries.

5.4.2.4 Magnesium-Carbon

The wastes from the production of this battery consist of scrap batteries, which for the typical plant is approximately 40,770 kg per year, and the sludge from treatment of chromic acid wastewater. The scrap batteries do not contain any potentially hazardous material when disposed of on land. The wastewater treatment sludge containing a mixture of chromium hydroxide and chromium carbonate is produced (on a dry basis) at the rate of 11.07 kg per 1000 kg of product. The sludge waste stream destined for land disposal was estimated to contain 40% by weight solids.

Tables 39, 40, and 41 show the quantities of hazardous wastes destined for land disposal from the magnesium-carbon primary battery industry for three time periods--1973, 1977, and 1983. Each table shows the quantity of active hazardous material, on a water free basis, in the waste stream together with the total amount of the waste stream based upon the waste factors derived in a previous section.

The projected increase of waste going to landfill between 1973 and 1977 is based on the discontinuance of the manufacture of bricks from solid waste from a plant in North Carolina. The result is a projected increase in waste going to landfill from the manufacture of this battery.

5.4.2.5 Zinc-Silver Oxide Battery

The wastes from this process are in the form of rejected batteries from the test and package step of the process. The wastes from the rejected batteries are 0.00109 kg of mercury, 0.0187 kg of zinc, and 0.0047 kg of silver oxide per 1000 kg of product. The waste cells from this production contain valuable materials and are sold to outside scrap reclaimers. Industry sources indicate that there are no hazardous wastes destined for land disposal from the production of this battery.

Tables 42, 43, and 44 show the quantities of hazardous wastes from the zinc-silver oxide primary battery industry for three time periods--1973, 1977, and 1983. Each table shows the quantity of active hazardous material, on a water free basis, in the waste stream together with the total amount of the waste stream based upon the waste factors derived in a previous section.

Table 36. 3692 Amount of Mercury Cell Hazardous Wastes Destined for Land Disposal (1973)

REGION/STATE		Zinc Metal kg	Mercury Metal kg	Mercuric Oxide kg	Total Waste Stream kg
IV	Alabama				
X	Alaska				
IX	Arizona				
VI	Arkansas				
IX	California				
VIII	Colorado				
I	Connecticut				
III	Delaware				
IV	Florida				
IV	Georgia				
IX	Hawaii				
X	Idaho				
V	Illinois	1,823	12.4	51.1	2,668
V	Indiana				
VII	Iowa				
VII	Kansas				
IV	Kentucky				
VI	Louisiana				
I	Maine				
III	Maryland				
I	Massachusetts				
V	Michigan				
V	Minnesota				
IV	Mississippi				
VII	Missouri				
VIII	Montana				
VII	Nebraska				
IX	Nevada				
I	New Hampshire				
II	New Jersey				
VI	New Mexico				
II	New York	3,074	21.0	86.3	4,498
IV	North Carolina	2,136	14.6	59.9	3,126
VIII	North Dakota				
V	Ohio				
VI	Oklahoma				
X	Oregon				
III	Pennsylvania				
I	Rhode Island				
IV	South Carolina	101.7	0.7	2.9	148.9
VIII	South Dakota				
IV	Tennessee				
VI	Texas				
VIII	Utah				
I	Vermont	330.5	2.3	9.3	483.7
III	Virginia				
X	Washington				
III	West Virginia				
V	Wisconsin	2,863	19.5	80.2	4,190
VIII	Wyoming				
TOTAL		10,328	70.5	289.7	15,115
Region	I	330.5	2.3	9.3	483.7
	II	3,074	21.0	86.3	4,498
	III	0	0	0	0
	IV	2,238	15.3	62.8	3,275
	V	4,686	31.9	131.3	6,858
	VI	0	0	0	0
	VII	0	0	0	0
	VIII	0	0	0	0
	IX	0	0	0	0
	X	0	0	0	0

Table 37. 3692 Amount of Mercury Cell Hazardous Wastes Destined for Land Disposal (1977)

REGION/STATE		Zinc Metal kg	Mercury Metal kg	Mercuric Oxide kg	Total Waste Stream kg
IV	Alabama				
X	Alaska				
IX	Arizona				
VI	Arkansas				
IX	California				
VIII	Colorado				
I	Connecticut				
III	Delaware				
IV	Florida				
IV	Georgia				
IX	Hawaii				
X	Idaho				
V	Illinois	911.5	3.2	13.1	1,318
V	Indiana				
VII	Iowa				
VII	Kansas				
IV	Kentucky				
VI	Louisiana				
I	Maine				
III	Maryland				
I	Massachusetts				
V	Michigan				
V	Minnesota				
IV	Mississippi				
VII	Missouri				
VIII	Montana				
VII	Nebraska				
IX	Nevada				
I	New Hampshire				
II	New Jersey				
VI	New Mexico				
II	New York	1,537	5.4	22.1	2,223
IV	North Carolina	1,068	3.7	15.3	1,545
VIII	North Dakota				
V	Ohio				
VI	Oklahoma				
X	Oregon				
III	Pennsylvania				
I	Rhode Island				
IV	South Carolina	50.9	0.2	0.8	62.9
VIII	South Dakota				
IV	Tennessee				
VI	Texas				
VIII	Utah				
I	Vermont	165.3	0.6	2.4	239.1
III	Virginia				
X	Washington				
III	West Virginia				
V	Wisconsin	1,432	5.0	20.6	2,071
VIII	Wyoming				
TOTAL		5,165	18.1	74.3	7,459
Region	I	165.3	0.6	2.4	239.1
	II	1,537	5.4	22.1	2,223
	III	0	0	0	0
	IV	1,119	3.9	16.1	1,608
	V	2,343	8.2	33.7	3,389
	VI	0	0	0	0
	VII	0	0	0	0
	VIII	0	0	0	0
	IX	0	0	0	0
	X	0	0	0	0

Table 38. 3692 Amount of Mercury Cell Hazardous Wastes Destined for Land Disposal (1983)

REGION/STATE		Zinc Metal kg	Mercury Metal kg	Mercuric Oxide kg	Total Waste Stream kg
IV	Alabama				
X	Alaska				
IX	Arizona				
VI	Arkansas				
IX	California				
VIII	Colorado				
I	Connecticut				
III	Delaware				
IV	Florida				
IV	Georgia				
IX	Hawaii				
X	Idaho				
V	Illinois	911.5	0.1	0.5	1,302
V	Indiana				
VII	Iowa				
VII	Kansas				
IV	Kentucky				
VI	Louisiana				
I	Maine				
III	Maryland				
I	Massachusetts				
V	Michigan				
V	Minnesota				
IV	Mississippi				
VII	Missouri				
VIII	Montana				
VII	Nebraska				
IX	Nevada				
I	New Hampshire				
II	New Jersey				
VI	New Mexico				
II	New York	1,537	0.2	0.9	2,196
IV	North Carolina	1,068	0.14	0.6	1,527
VIII	North Dakota				
V	Ohio				
VI	Oklahoma				
X	Oregon				
III	Pennsylvania				
I	Rhode Island				
IV	South Carolina	50.9	0.01	0.03	62.9
VIII	South Dakota				
IV	Tennessee				
VI	Texas				
VIII	Utah				
I	Vermont	165.3	0.02	0.09	235.3
III	Virginia				
X	WAshington				
III	West Virginia				
V	Wisconsin	1,432	0.20	0.80	2,046
VIII	Wyoming				
TOTAL		5,165	0.67	2.9	7,369
Region I		165.3	0.02	0.09	235.3
II		1,537	0.20	0.90	2,196
III		0	0	0	0
IV		1,119	0.15	0.6	1,590
V		2,343	0.30	1.3	3,348
VI		0	0	0	0
VII		0	0	0	0
VIII		0	0	0	0
IX		0	0	0	0
X		0	0	0	0

Table 39. 3692 Amount of Magnesium-Carbon Battery Hazardous Wastes Destined for Land Disposal (1973)

REGION/STATE		Chromium Hydroxide-Chromium Carbonate Sludge (Dry) kg	Total Sludge Waste Stream kg	
IV	Alabama			
X	Alaska			
IX	Arizona			
VI	Arkansas			
IX	California			
VIII	Colorado			
I	Connecticut			
III	Delaware			
IV	Florida	1,040	2,600	
IV	Georgia			
IX	Hawaii			
X	Idaho			
V	Illinois			
V	Indiana			
VII	Iowa			
VII	Kansas			
IV	Kentucky			
VI	Louisiana			
I	Maine			
III	Maryland			
I	Massachusetts			
V	Michigan			
V	Minnesota			
IV	Mississippi			
VII	Missouri			
VIII	Montana			
VII	Nebraska			
IX	Nevada			
I	New Hampshire			
II	New Jersey			
VI	New Mexico			
II	New York			
IV	North Carolina			
VIII	North Dakota			
V	Ohio			
VI	Oklahoma			
X	Oregon			
III	Pennsylvania			
I	Rhode Island			
IV	South Carolina			
VIII	South Dakota			
IV	Tennessee			
VI	Texas	9,046	22,615	
VIII	Utah			
I	Vermont			
III	Virginia			
X	WAshington			
III	West Virginia			
V	Wisconsin			
VIII	Wyoming			
TOTAL		10,086	25,215	
Region	I	0	0	
	II	0	0	
	III	0	0	
	IV	1,040	2,600	
	V	0	0	
	VI	9,046	22,615	
	VII	0	0	
	VIII	0	0	
	IX	0	0	
	X	0	0	

Table 40. 3692 Amount of Magnesium-Carbon Battery Hazardous Wastes Destined for Land Disposal (1977)

REGION/STATE	Chromium Hydroxide-Chromium-Carbonate Sludge (Dry) kg	Total Sludge Waste Stream kg	
IV Alabama			
X Alaska			
IX Arizona			
VI Arkansas			
IX California			
VIII Colorado			
I Connecticut			
III Delaware			
IV Florida	1,216	3,039	
IV Georgia			
IX Hawaii			
X Idaho			
V Illinois			
V Indiana			
VII Iowa			
VII Kansas			
IV Kentucky			
VI Louisiana			
I Maine			
III Maryland			
I Massachusetts			
V Michigan			
V Minnesota			
IV Mississippi			
VII Missouri			
VIII Montana			
VII Nebraska			
IX Nevada			
I New Hampshire			
II New Jersey			
VI New Mexico			
II New York			
IV North Carolina	35,985	89,964	
VIII North Dakota			
V Ohio			
VI Oklahoma			
X Oregon			
III Pennsylvania			
I Rhode Island			
IV South Carolina			
VIII South Dakota			
IV Tennessee			
VI Texas	10,575	25,437	
VIII Utah			
I Vermont			
III Virginia			
X WAshington			
III West Virginia			
V Wisconsin			
VIII Wyoming			
TOTAL	47,776	119,440	
Region I	0	0	
II	0	0	
III	0	0	
IV	37,201	93,003	
V	0	0	
VI	10,575	26,437	
VII	0	0	
VIII	0	0	
IX	0	0	
X	0	0	

Table 41. 3692 Amount of Magnesium-Carbon Battery Hazardous Wastes Destined for Land Disposal (1983)

REGION/STATE		Chromium Hydroxide-Chromium Carbonate Sludge (Dry) kg	Total Sludge Waste Stream kg	
IV	Alabama			
X	Alaska			
IX	Arizona			
VI	Arkansas			
IX	California			
VIII	Colorado			
I	Connecticut			
III	Delaware			
IV	Florida	1,216	3,039	
IV	Georgia			
IX	Hawaii			
X	Idaho			
V	Illinois			
V	Indiana			
VII	Iowa			
VII	Kansas			
IV	Kentucky			
VI	Louisiana			
I	Maine			
III	Maryland			
I	Massachusetts			
V	Michigan			
V	Minnesota			
IV	Mississippi			
VII	Missouri			
VIII	Montana			
VII	Nebraska			
IX	Nevada			
I	New Hampshire			
II	New Jersey			
VI	New Mexico			
II	New York			
IV	North Carolina	35,985	89,964	
VIII	North Dakota			
V	Ohio			
VI	Oklahoma			
X	Oregon			
III	Pennsylvania			
I	Rhode Island			
IV	South Carolina			
VIII	South Dakota			
IV	Tennessee			
VI	Texas	10,575	26,437	
VIII	Utah			
I	Vermont			
III	Virginia			
X	WAshington			
III	West Virginia			
V	Wisconsin			
VIII	Wyoming			
TOTAL		47,776	119,440	
Region I		0	0	
	II	0	0	
	III	0	0	
	IV	37,201	93,003	
	V	0	0	
	VI	10,575	26,437	
	VII	0	0	
	VIII	0	0	
	IX	0	0	
	X	0	0	

Table 42. 3692 Amount of Zinc-Silver Oxide Battery Hazardous Wastes* (1973)

REGION/STATE	Zinc Metal kg	Silver Oxide kg	Mercury Metal kg	Total Waste Stream, kg
IV Alabama				
X Alaska				
IX Arizona				
VI Arkansas				
IX California	0.3	0.06	136.2	0.01
VIII Colorado	0.4	0.11	227.0	0.02
I Connecticut				
III Delaware				
IV Florida				
IV Georgia				
IX Hawaii				
X Idaho				
V Illinois				
V Indiana	0.1	0.03	54.5	0.01
VII Iowa				
VII Kansas				
IV Kentucky				
VI Louisiana				
I Maine				
III Maryland	0.1	0.03	54.5	0.01
I Massachusetts				
V Michigan				
V Minnesota				
IV Mississippi				
VII Missouri	0.5	0.13	272.4	0.03
VIII Montana				
VII Nebraska				
IX Nevada				
I New Hampshire				
II New Jersey				
VI New Mexico				
II New York	0.6	0.14	308.7	0.03
IV North Carolina	4.1	1.02	2,179	0.24
VIII North Dakota				
V Ohio				
VI Oklahoma				
X Oregon				
III Pennsylvania				
I Rhode Island	0.9	0.23	499.4	0.05
IV South Carolina				
VIII South Dakota				
IV Tennessee				
VI Texas				
VIII Utah				
I Vermont	1.1	0.29	608.4	0.07
III Virginia				
X WAshington				
III West Virginia				
V Wisconsin	1.7	0.43	908.0	0.10
VIII Wyoming				
TOTAL	9.8	2.5	5,248	0.6
Region I	2.0	0.52	1,108	0.12
II	0.6	0.14	309.0	0.03
III	0.1	0.03	54.5	0.01
IV	4.1	1.02	2,179	0.24
V	1.8	0.46	962.5	0.11
VI	0	0	0	0
VII	0.5	0.13	272.4	0.03
VIII	0.4	0.11	227.0	0.02
IX	0.3	0.06	136.2	0.01
X	0	0	0	0

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* Industry Sources indicated none of these wastes are destined for land disposal.

Table 43. 3692 Amount of Zinc-Silver Oxide Battery Hazardous Wastes* (1977)

REGION/STATE		Zinc Metal kg	Silver Oxide kg	Mercury Metal kg	Total Waste Stream, kg
IV	Alabama				
X	Alaska				
IX	Arizona				
VI	Arkansas				
IX	California	0.4	0.07	0.01	159.2
VIII	Colorado	0.5	0.12	0.02	265.4
I	Connecticut				
III	Delaware				
IV	Florida				
IV	Georgia				
IX	Hawaii				
X	Idaho				
V	Illinois				
V	Indiana	0.1	0.03	0.01	63.7
VII	Iowa				
VII	Kansas				
IV	Kentucky				
VI	Louisiana				
I	Maine				
III	Maryland	0.1	0.03	0.01	63.7
I	Massachusetts				
V	Michigan				
V	Minnesota				
IV	Mississippi				
VII	Missouri	0.6	0.15	0.04	318.4
VIII	Montana				
VII	Nebraska				
IX	Nevada				
I	New Hampshire				
II	New Jersey				
VI	New Mexico				
II	New York	0.7	0.17	0.04	360.9
IV	North Carolina	4.8	1.20	0.28	2,547
VIII	North Dakota				
V	Ohio				
VI	Oklahoma				
X	Oregon				
III	Pennsylvania				
I	Rhode Island	1.1	0.27	0.06	583.8
IV	South Carolina				
VIII	South Dakota				
IV	Tennessee				
VI	Texas				
VIII	Utah				
I	Vermont	1.3	0.33	0.08	711.2
III	Virginia				
X	WAshington				
III	West Virginia				
V	Wisconsin	2.0	0.50	0.12	1,061
VIII	Wyoming				
TOTAL		11.6	2.9	0.7	6,134.3
Region	I	2.4	0.60	0.14	1,295
	II	0.7	0.17	0.04	360.9
	III	0.1	0.03	0.01	63.7
	IV	4.8	1.20	0.28	2,547
	V	2.1	0.53	0.13	1,125
	VI	0	0	0	0
	VII	0.6	0.15	0.04	318.4
	VIII	0.5	0.12	0.02	265.4
	IX	0.4	0.07	0.01	159.2
	X	0	0	0	0

* Industry sources indicated none of these wastes are destined for land disposal.

Table 44. 3692 Amount of Zinc-Silver Oxide Battery Hazardous Wastes* (1983)

REGION/STATE		Zinc Metal kg	Silver Oxide kg	Mercury Metal kg	Total Waste Stream, kg
IV	Alabama				
X	Alaska				
IX	Arizona				
VI	Arkansas				
IX	California	0.4	0.07	0.01	159.2
VIII	Colorado	0.5	0.12	0.02	265.4
I	Connecticut				
III	Delaware				
IV	Florida				
IV	Georgia				
IX	Hawaii				
X	Idaho				
V	Illinois				
V	Indiana	0.1	0.03	0.01	63.7
VII	Iowa				
VII	Kansas				
IV	Kentucky				
VI	Louisiana				
I	Maine				
III	Maryland	0.1	0.03	0.01	63.7
I	Massachusetts				
V	Michigan				
V	Minnesota				
IV	Mississippi				
VII	Missouri	0.6	0.15	0.04	318.4
VIII	Montana				
VII	Nebraska				
IX	Nevada				
I	New Hampshire				
II	New Jersey				
VI	New Mexico				
II	New York	0.7	0.17	0.04	360.9
IV	North Carolina	4.8	1.20	0.28	2,547
VIII	North Dakota				
V	Ohio				
VI	Oklahoma				
X	Oregon				
III	Pennsylvania				
I	Rhode Island	1.1	0.27	0.05	583.8
IV	South Carolina				
VIII	South Dakota				
IV	Tennessee				
VI	Texas				
VIII	Utah				
I	Vermont	1.3	0.33	0.08	711.2
III	Virginia				
X	WAshington				
III	West Virginia				
V	Wisconsin	2.0	0.50	0.12	1,061
VIII	Wyoming				
TOTAL		11.6	2.9	0.7	6,134.3
Region	I	2.4	0.60	0.14	1,295
	II	0.7	0.17	0.04	360.9
	III	0.1	0.03	0.01	63.7
	IV	4.8	1.20	0.28	2,547
	V	2.1	0.53	0.13	1,125
	VI	0	0	0	0
	VII	0.6	0.15	0.04	318.4
	VIII	0.5	0.12	0.02	265.4
	IX	0.4	0.07	0.01	159.2
	X	0	0	0	0

* Industry sources indicated none of these wastes are destined for land disposal.

5.4.2.6 Other Primary Batteries

5.4.2.6.1 Carbon-Zinc Air Cell

Wastes from the typical plant stem entirely from rejected complete cells. The wastes consist of zinc in the amount of 0.294 kg per 1000 kg of product or 453 kg per year, and mercury at 0.00117 kg per 1000 kg of product or 1.80 kg per year. The waste stream of the typical plant contains 15,400 kg of cell scrap per year.

5.4.2.6.2 Lead-Acid Reserve Cell

The potentially hazardous wastes from the production of lead-acid reserve cells come from quality control rejected batteries, scrap metals, and potentially from future wastewater treatment sludges from wastewater treatment for nickel and lead in the plant effluent. At the present time, a wastewater treatment system is in the planning stages at one plant, but now the effluent goes to a municipal sewage system. The wastes from rejected batteries and scrap consists of 182 kg of lead and 104 kg of nickel per 1000 kg of product. The quantity of wastewater treatment sludges is estimated to be 2.86 kg per 1000 kg of product on a dry basis. The total sludge waste stream was estimated to contain 35% solids.

5.4.2.6.3 Mercury Weston Cell

The potentially hazardous wastes from the production of this battery consist of rejected batteries. These wastes consist of mercury at 1.854 kg per 1000 kg of product or 1.680 kg per year, mercuric sulfate at 0.618 kg per 1000 kg of product, cadmium sulfate at 0.795 kg per 1000 kg of product, and cadmium at 0.442 kg per 1000 kg of product. The waste stream consists of about 9 kg batteries per year.

Tables 45, 46, and 47 show the quantities of hazardous wastes destined for land disposal from the "other" primary batteries industries for three time periods--1973, 1977, 1983. Each table shows the quantity of active hazardous material, on a water free basis, in the waste stream together with the total amount of the waste stream based upon the waste factors derived in a previous section.

5.4.3 Summary of Hazardous Waste Streams

The description of wastes as hazardous for the present study followed the guidance given by EPA Hazardous Waste Management Division that all wastes which pose a potential health or environmental hazard upon final disposal shall be considered hazardous. The majority of hazardous wastes considered in the present study were specifically designated by the EPA for study (cadmium, chromium, copper, lead, mercury, and zinc). The remaining wastes were deemed to be essentially inert upon final disposal,

Table 45. 3692 Amount of Other Primary Battery Hazardous Wastes Destined for Land Disposal (1973)

REGION/STATE	Lead Metal (Dry basis) kg	Nickel Metal (Dry) kg	Cadmium Sulfate (Dry) kg	Merc. Sulfate (Dry) kg	Cadmium Metal (Dry) kg	Merc. Metal (Dry) kg	Zinc Metal (Dry) kg	Sludge Cont. Ni& Pb(Dry) kg	Sludge Cont. Ni& Pb(Wet) kg	Scrap Ni &Pb kg	Total Waste Stream kg
IV Alabama											
X Alaska											
IX Arizona											
VI Arkansas											
IX California											
VIII Colorado											
I Connecticut											
III Delaware											
IV Florida											
IV Georgia											
IX Hawaii											
X Idaho											
V Illinois											
V Indiana											
VII Iowa											
VII Kansas											
IV Kentucky											
VI Louisiana											
I Maine											
III Maryland											
I Massachusetts											
V Michigan											
V Minnesota											
IV Mississippi											
VII Missouri	231.3	132.2									
VIII Montana						1.9	467.2	3.6	10.4	419.5	15,890
VII Nebraska											
IX Nevada											
I New Hampshire											
II New Jersey											
VI New Mexico						1.9	467.2				15,890
II New York											
IV North Carolina											
VIII North Dakota											
V Ohio											
VI Oklahoma						1.8	453.8				15,436
X Oregon											
III Pennsylvania											
I Rhode Island			0.9*	0.5*	0.5*	1.8*					
IV South Carolina											90.8*
VIII South Dakota											
IV Tennessee											
VI Texas											
VIII Utah											
I Vermont	7,271	4,155									
III Virginia								114.3	326.6	13,184	30,000
X WAshington											
III West Virginia											
V Wisconsin											
VIII Wyoming											
TOTAL	7,502	4,287	0.9	0.5	0.5	7.4	1,388	117.9	337.0	13,604	77,307
Region I	7,271	4,155	0.9	0.5	0.5						
II						1.8	0	114,3	326.6	13,184	30,091
III						1.9	467.2				15,890
IV						0	0				0
V						0	0				0
VI						1.8	453.8				15,436
VII	231.3	132.2				0	0				0
VIII						1.9	467.2	3.6	10.4	419.5	15,890
IX						0	0				0
X						0	0				0
						0	0				0

*Industry source indicated these wastes are being stored in plant.

Table 46. 3692 Amount of Other Primary Battery Hazardous Wastes Destined for Land Disposal (1977)

REGION/STATE	Lead Metal (Dry basis) kg	Nickel Metal (Dry) kg	Cadmium Sulfate (Dry) kg	Merc. Sulfate (Dry) kg	Cadmium Metal (Dry) kg	Merc. Metal (Dry) kg	Zinc Metal (Dry) kg	Sludge Cont. Ni& Pb(Dry) kg	Sludge Cont. Ni& Pb(Wet) kg	Scrap Ni &Pb kg	Total Waste Stream kg
IV Alabama											
X Alaska											
IX Arizona											
VI Arkansas											
IX California											
VIII Colorado											
I Connecticut											
III Delaware											
IV Florida											
IV Georgia											
IX Hawaii											
X Idaho											
V Illinois											
V Indiana											
VII Iowa											
VII Kansas											
IV Kentucky											
VI Louisiana											
I Maine											
III Maryland											
I Massachusetts											
V Michigan											
V Minnesota											
IV Mississippi											
VII Missouri	2,727	1,558				2.2	546.2	42.9	122.5	4,944	18,575
VIII Montana											
VII Nebraska											
IX Nevada											
I New Hampshire											
II New Jersey						2.2	546.2				18,575
VI New Mexico											
II New York											
IV North Carolina											
VIII North Dakota											
V Ohio						2.1	530.5				18,045
VI Oklahoma											
X Oregon											
III Pennsylvania											
I Rhode Island			0*	0*	0*	0*					0*
IV South Carolina											
VIII South Dakota											
IV Tennessee											
VI Texas											
VIII Utah											
I Vermont	10,906	6,233						171.5	489.9	19,776	
III Virginia											
X Washington											
III West Virginia											
V Wisconsin											
VIII Wyoming											
TOTAL	13,633	7,791	0	0	0	6.5	1,623	214.4	612.4	24.720	55,195
Region I	10,906	6,233	0	0	0	0	0	171.5	489.9	19,776	0
II						2.2	546.2				18,575
III						0	0				0
IV						0	0				0
V						2.1	530.5				18,045
VI						0	0				0
VII	2,727	1,558				2.2	546.2	42.9	122.5	4,944	18,575
VIII						0	0				0
IX						0	0				0
X						0	0				0

*Industry Source indicated reclaim of scrap cells.

Table 47. 3692 Amount of Other Primary Battery Hazardous Wastes Destined for Land Disposal (1983)

REGION/STATE		Lead Metal (Dry basis) kg	Nickel Metal (Dry) kg	Cadmium Sulfate (Dry) kg	Merc. Sulfate (Dry) kg	Cadmium Metal (Dry) kg	Merc. Metal (Dry) kg	Zinc Metal (Dry) kg	Sludge Cont.NI& Pb(Dry) kg	Sludge Cont. NI& Pb(Wet) kg	Scrap NI &Pb kg	Total Waste Stream kg
IV	Alabama											
X	Alaska											
IX	Arizona											
VI	Arkansas											
IX	California											
VIII	Colorado											
I	Connecticut											
III	Delaware											
IV	Florida											
IV	Georgia											
IX	Hawaii											
X	Idaho											
V	Illinois											
V	Indiana											
VII	Iowa											
VII	Kansas											
IV	Kentucky											
VI	Louisiana											
I	Maine											
III	Maryland											
I	Massachusetts											
V	Michigan											
V	Minnesota											
IV	Mississippi											
VII	Missouri	3,636	2,078									
VIII	Montana						2.3	568.1	57.2	163.3	6,592	19,322
VII	Nebraska											
IX	Nevada											
I	New Hampshire											
II	New Jersey											
VI	New Mexico						2.3	568.1				
II	New York											19,322
IV	North Carolina											
VIII	North Dakota											
V	Ohio											
VI	Oklahoma						2.2	551.8				
X	Oregon											18,770
III	Pennsylvania											
I	Rhode Island											
IV	South Carolina			0*	0*	0*	0*					0*
VIII	South Dakota											
IV	Tennessee											
VI	Texas											
VIII	Utah											
I	Vermont	14,542	8,310									
III	Virginia								228.6	653.2	26,368	
X	WAshington											
III	West Virginia											
V	Wisconsin											
VIII	Wyoming											
TOTAL		18,178	10,388	0	0	0	6.8	1,688	285.8	816.5	32,960	57,414
Region	I	14,542	8,310	0	0	0	0	0	228.6	653.2		0
	II						2.3	568.1				19,322
	III						0	0				0
	IV						0	0				0
	V						2.2	551.8				18,770
	VI						0	0				0
	VII	3,636	2,078				2.3	568.1	57.2	163.3	6,592	19,322
	VIII						0	0				0
	IX						0	0				0
	X						0	0				0

*Industry Source indicated reclaim of scrap cells.

except for silver and nickel which were designated as hazardous on the basis of their chemical and toxicological properties and solubilities.

The EPA has not yet established standards for allowable concentrations of hazardous materials in soils. As part of a hazardous waste study conducted by EPA, TRW, Inc. (33) developed provisional limitations for soils; in most instances provisional soil and water limitations were identical. Based on this data, allowable concentrations of hazardous substances in soil are as follows:

mercury and its compounds	5µg/kg
cadmium and its compounds	10µg/kg
lead and its compounds	50µg/kg
nickel and its compounds	5 mg/kg
zinc and its compounds	5 mg/kg
chromium (hexavalent) and its compounds	5µg/kg

Soil and sludge samples found in this study have exceeded these values as seen in Section 6.3.

Table 48 presents a condensed summary of hazardous waste streams based on the waste characterization of the storage and primary batteries industries, which were selected for study with regard to treatment and disposal technology and the associated costs.

Table 48. Battery Production Hazardous Wastes

Category and Process SIC 3691, Storage Batteries	Waste Stream and Hazardous Constituents
(a) Lead-Acid	(1) Wastewater effluent treatment sludges – containing suspended lead, lead sulfate, and lead hydroxide or calcium sulfate sludge containing lead.
(b) Nickel-Cadmium	(2) Wastewater effluent treatment sludges – containing cadmium hydroxide and nickel hydroxide.
	(3) Rejected and scrap cells — containing cadmium and nickel.
(c) Cadmium-Silver Oxide	(4) Wastewater effluent treatment sludges — containing cadmium hydroxide and silver oxide (reclaimed).
	(5) Rejected and scrap cells — containing cadmium and silver oxide (reclaimed).
(d) Zinc-Silver Oxide	(6) Rejected and scrap cells — containing zinc oxide-hydroxide, silver oxide, and mercury (reclaimed).
Category and Process SIC 3692, Primary Batteries	
(a) Carbon-Zinc	(7) Rejected and scrap batteries — containing mercury and zinc.
(b) Air Cell	(8) Rejected and scrap batteries — containing mercury and zinc.
(c) Alkaline-Manganese	(9) Rejected and scrap batteries — containing mercury and zinc.
(d) Mercury	(10) Scrap batteries and furnace residue - containing mercury and zinc.

Table 48. Battery Production Hazardous Wastes - continued

Category and Process SIC 3692, Primary Batteries	Waste Stream and Hazardous Constituents
(e) Weston Mercury Cell	(11) Rejected and scrap batteries — containing mercury, mercurous sulfate, cadmium-mercury, and cadmium sulfate
(f) Magnesium-Carbon	(12) Wastewater effluent treatment sludges - containing trivalent chromium carbonate hydroxide.
(g) Zinc-Silver Oxide	(13) Rejected and scrap batteries — containing zinc, silver, and mercury (reclaimed).
(h) Lead Acid Reserve	(14) Rejected and scrap batteries — containing lead and nickel.
(i) Magnesium Reserve Cells	(15) Wastewater treatment sludges - containing nickel and lead.
	(16) Rejected and scrap batteries — containing silver chloride (reclaimed) or copper chloride.

6.0 TREATMENT AND DISPOSAL TECHNOLOGY

6.1 Introduction

Land-destined hazardous wastes from the battery industry originate either directly from the manufacturing processes or from air or water pollution control systems on these processes. The wastes from the two SIC codes of the battery industries are, in general, distinct from each other. Land-destined wastes from the storage batteries industry (SIC 3691) are mainly high volume sludges resulting from water treatment along with some reject cells. Wastes from the primary batteries industry (SIC 3692) almost exclusively consist of reject or scrap cells. The volume is much smaller than in the former case, but the hazardous waste portion is relatively higher.

The form of technology used in the treatment and disposal depends on several factors:

(a) The volume of hazardous waste involved. Small volume wastes can be treated and disposed of by a number of methods of available technology without major economic impact. Large volume wastes do not usually have this latitude.

(b) The chemical composition of the waste. Both the hazardous chemicals involved and the concentrations in which they are found determine the necessary treatment and disposal technology required.

(c) The local regulations. In the absence of regulations, treatment and disposal of hazardous wastes is usually accomplished by the lowest cost methods — land dumping or use of low cost landfilling.

(d) The geographical location. Both the technologies and the costs are more favorable in the dry portions of western U.S. than in eastern U.S. When rainfall is slight, both liquid and solid hazardous wastes can be disposed of with less danger of environmental contamination. The numerous isolated thinly populated western areas available for hazardous waste disposal also minimize the effect on the population.

(e) The availability of land. Some plants have little or no on-site disposal space available. This factor influences both location and methods of treatment and disposal.

Therefore, treatment and disposal options must be considered in light of the ambient climate, geology, and population pattern. The following description of the existing treatment and disposal technologies includes these considerations.

The hazardous wastes from the battery industries may generally be classified into two categories. The first is high volume sludges with low concentrations of hazardous materials, and the second is low volume sludges and scrap containing relatively high concentrations of hazardous materials. The hazardousness of the waste materials and related discussions are presented in Appendix A.

The general treatment and disposal technologies for handling battery production hazardous wastes can be classified into the following categories:

(a) Reducing the amount of hazardous material that has to be disposed of, for example, by recycling;

(b) Concentrating a large volume low-concentration waste stream into a smaller more concentrated waste stream;

(c) Utilization of the waste by chemical fixation; and

(d) Disposal of the waste by burial, storage, or landfill.

The specific treatment and disposal technology used by the storage and primary batteries industries are given in the following sections. Tables 49 and 50 summarize the types and quantities of hazardous wastes from a typical plant production standpoint.

6.2 Treatment and Disposal in Storage Batteries Manufacture (SIC 3691)

The only segments of this subcategory having any significant land-destined hazardous wastes are the lead-acid storage battery and the nickel-cadmium storage battery. As shown in Table 49, the potentially hazardous wastes from the cadmium-silver oxide and zinc-silver oxide batteries are relcaimed for their economic value.

6.2.1 Lead-Acid Battery

The character of the hazardous wastewater treatment sludges from a lead-acid battery plant is determined largely by the type of water treatment used. The amount of the treatment sludges produced is difficult to characterize or assess at the present time due to the absence of EPA water effluent guidelines or pretreatment standards for wastewater from a lead acid battery plant. In order to assess the quantity of potentially hazardous treatment sludges, in the absence of guidelines for this industry, an engineering model treatment was developed based upon current practices in the industry. The results of this model give quantities of lead in the treated effluent and the amount of lead removed as sludge which can be assumed to be the maximum amount to be destined for land disposal.

Table 49. Summary of Typical Plant Treatment and Disposal of Land Destined Hazardous Wastes From Storage Batteries Manufacture (SIC 3691)

Battery Type	1973 Total Industry Production (kkg/yr)	Hazardous Waste Stream	Typical Plant Production (kkg/yr)	Amount of Hazardous Constituents in Typical Plant Waste Stream (kkg/yr)	Quantity of Plant Total Waste Stream (Wet Basis) (kkg/yr)
(a) Lead Acid	1,081,187	(1) Lead containing sludge resulting from lime wastewater treatment		2.6	17,290
		(2) Lead containing sludge resulting from caustic wastewater treatment	8200	2.6	4.46
(b) Nickel-Cadmium	4,005	(1) Sludge from caustic wastewater treatment containing cadmium hydroxide and nickel hydroxide		3.1	8.9
		(2) Rejected and scrap cells containing cadmium and nickel	447	3.0	5.4
(c) Cadmium-Silver Oxide	Not Available	(1) Wastewater treatment sludge containing silver oxide and cadmium hydroxide		0.3	0.5 (reclaimed)
		(2) Rejected and scrap cells containing cadmium and silver oxide	36.2	0.3	0.4 (reclaimed)
(d) Zinc-Silver Oxide	Not Available	(1) Rejected and scrap cells containing zinc oxide-hydroxide, silver oxide, and mercury	Not available	Not available	Not available (reclaimed)

Table 50. Summary of Typical Plant Treatment and Disposal of Land Destined Hazardous Wastes From Primary Batteries Manufacture (SIC 3692)

Battery Type	1973 Total Industry Production (kkg/yr)	Hazardous Waste Streams	Typical Plant Production (kkg/yr)	Amount of Hazardous Constituents in Typical Plant Waste Stream (kkg/yr)	Quantity of Plant Total Waste Stream (Wet Basis) (kkg/yr)
(a) Carbon Zinc	95,900	Rejected and Scrap Cells	2,270	9.2	22.7
(b) Carbon Zinc Air Cell	Not Available	Rejected and Scrap Cells	1,500	0.45	15.4
(c) Alkaline-Manganese	14,000	Rejected and Scrap Cells	2,000	3.5	20
(d) Mercury	1,845	Scrap Cells and Furnace Residue	450	2.6	3.6
(e) Weston Mercury Cell	0.9	Rejected and Scrap Cells	0.9	0.003	0.009
(f) Magnesium Carbon	3,700	Wastewater Effluent Treatment Sludge	1,350	15	37.5
(g) Zinc-Silver Oxide	525	Rejected and Scrap Cells	59.1	0.001	0.59 (reclaimed)
(h) Lead Acid Reserve	Not Available	(1) Scrap and Rejected Cells (2) Wastewater Treatment Sludge	45.4	13 0.13	14.9 0.37
(i) Magnesium Reserve	Not Available	None	Not Available	None	Not Available

Currently, wastewater effluent from the battery plant typically goes to a municipal waste treatment plant. Treatment of lead waste in a municipal system may cause high concentrations of lead in sludge which will ultimately be transported and deposited in a landfill or in the effluent from the treatment plant. It is, therefore, assumed that pretreatment standards will be set up by regulatory agencies requiring many battery plants to remove lead in the effluent to the same degree as that required for discharge to surface waters.

Current practices of wastewater treatment in the lead-acid battery industry include the use of several methods, neutralization, precipitation, sedimentation, and filtration, for removing lead from waste streams. The untreated lead wastes generated by the battery industry typically fall within the following concentrations:

dissolved	0.5 ppm to 25 ppm;
suspended	5 ppm to 48 ppm.

The wastewater generated varies from 42 to 290 liters per battery produced. (Dry charge production generally results in more wastewater and greater amounts of waste lead than wet charge production).

A survey of eight battery plants indicated that simple sedimentation was relatively ineffective in removing insoluble lead particulates from waste streams.(21) Data reported for plants using pH adjustment followed by settling was as follows:

Treatment Chemical	pH	Settling Time (hr)	Effluent Lead (mg/l)	
			Dissolved	Suspended
Lime	6.8	30	0.30	0.18
Caustic	5.5	1	0.60	1.0
Ammonia	7.8	0	1.9	22.0

Note: Use of ammonia as a treatment chemical for pH adjustment may not be recommended without adequate precautions due to formation of soluble lead complexes.

There is a relationship between the pH necessary for precipitation, the treatment chemical and the settling time, which are variables in this data, however, simple sedimentation is shown to be ineffective in reduction of suspended lead. The removal of the finely suspended lead particles (less than two microns) from the wastewater, becomes difficult from a settling time standpoint, even if very little of the lead is dissolved. Flocculating agents have been used to increase the suspended solids removal rate. This would have the added effect, however, of increasing the impurity of the lead removed. The final result would be to decrease the possibility of reuse of the recovered product, creating a land disposal problem.

An environmentally more desirable method of removing small concentrations of suspended solids is by use of filtration. Pilot plant work showed initial success with filtration of lead wastes. A 900 liter per hour flow was used with an initial suspended lead particle concentration of 5 mg per liter. A dual media filter revealed the following results.(22)

Chemical	pH	Lead Concentration (mg/l) after: Sedimentation	Filtration
Ferric Sulfate (@45 mg per liter Iron)	6.0	0.25	0.030
Lime (@ 260 mg per liter) plus Ferric Sulfate (@20 mg per liter Iron)	10.0	0.25	0.029
Lime (@ 600 mg per liter)	11.5	0.20	0.019

Although admittedly on a pilot plant scale, the filtration reduced the lead hydroxide concentration by an order of magnitude. The lead recovered from this process could possibly be returned to the smelter.

The lead waste from battery production falls into two categories; dissolved and suspended. Both lime and caustic have proven to be effective in reducing the dissolved lead concentration to less than 0.5 mg per liter. The optimum pH for minimizing the dissolved lead has been established and the data indicates that it is approximately 9.3. Another possible approach is the use of carbonate for the chemical precipitating agent. Lead carbonate is extremely insoluble in water, allowing lead to be precipitated and filtered out to the same approximate level of 0.5 mg per liter. (23)

Figure 24 shows the lead waste resulting from the battery manufacturing process. In this case, sodium hydroxide or lime is used as the treatment chemical. The wastes from the treatment system destined for land disposal are wastewater treatment sludges, the quantities of which are based upon the modeled treatment system of neutralization, chemical precipitation,and settling or filtration.

These waste sludges consist of lead hydroxide and lead sulfate at 0.541 kg per 1000 kg of product (80% solids basis) for those plants using sodium hydroxide neutralization. The composition of the sludge typically will include lead sulfate (0.293 kg per 1000 kg), lead hydroxide (0.140 kg per 1000 kg) with a water content ranging from 20 to 65%. For those plants using lime neutralization, a calcium sulfate sludge is produced of 735 kg (dry basis) per 1000 kg of product. The composition of the

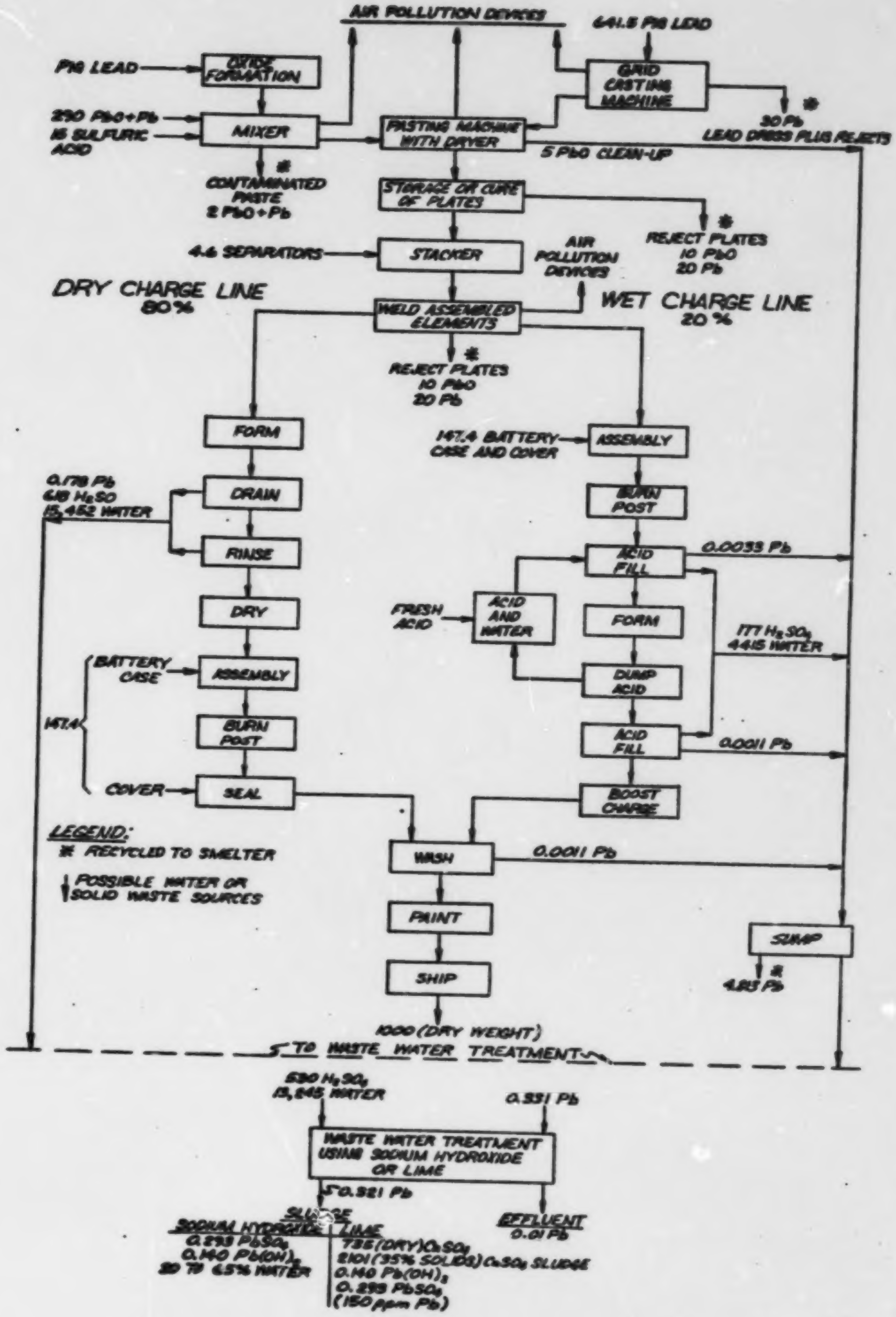
AIR POLLUTION DEVICES
641.5 PIG LEAD
PIG LEAD
OXIDE FORMATION
GRID CASTING MACHINE
290 PbO+Pb
15 SULFURIC ACID
MIXER
PASTING MACHINE WITH DRYER
✱
30 Pb
LEAD DROSS PLUS REJECTS
5 PbO CLEAN-UP
✱
CONTAMINATED PASTE
2 PbO+Pb
STORAGE OR CURE OF PLATES
✱
REJECT PLATES
10 PbO
20 Pb
4.6 SEPARATORS
STACKER
AIR POLLUTION DEVICES
DRY CHARGE LINE
80%
WELD ASSEMBLED ELEMENTS
WET CHARGE LINE
20 %
✱
REJECT PLATES
10 PbO
20 Pb
FORM
147.4 BATTERY CASE AND COVER
ASSEMBLY
0.178 Pb
618 H₂SO
15,452 WATER
DRAIN
BURN POST
RINSE
ACID FILL
0.0033 Pb
DRY
FRESH ACID
ACID AND WATER
FORM
177 H₂SO₄
4415 WATER
BATTERY CASE
ASSEMBLY
DUMP ACID
147.4
BURN POST
ACID FILL
0.0011 Pb
COVER
SEAL
BOOST CHARGE
LEGEND:
✱ RECYCLED TO SMELTER
POSSIBLE WATER OR SOLID WASTE SOURCES
WASH
0.0011 Pb
PAINT
SUMP
✱
4.815 Pb
SHIP
1000 (DRY WEIGHT)
TO WASTE WATER TREATMENT
530 H₂SO₄
13,845 WATER
0.331 Pb
WASTE WATER TREATMENT USING SODIUM HYDROXIDE OR LIME
0.321 Pb
SLUDGE
SODIUM HYDROXIDE
0.293 PbSO₄
0.140 Pb(OH)₂
30 TO 65% WATER
LIME
735 (DRY) CaSO₄
2101 (35% SOLIDS) CaSO₄ SLUDGE
0.140 Pb(OH)₂
0.293 PbSO₄
(150 ppm Pb)
EFFLUENT
0.01 Pb

Figure 24. Major Production Operations in Lead-Acid Storage Battery Manufacture

sludge typically will include calcium sulfate (2101 kg per 1000 kg at 35% solids basis), lead hydroxide (0.140 kg per 1000 kg), lead sulfate (0.293 kg per 1000 kg) with a lead content of approximately 150 mg per liter.

The cost of the waste treatment systems described above for a lead-acid battery plant varies according to volume of effluent processed. Typical cost figures for capital costs in 1973 dollars for a dry charge plant can vary from $112,500 to $260,000 as volume of effluent varies from 378,500 liters (1000 gallons) to 3,785,000 liters (1 million gallons) a day. For a wet charge plant with effluent ranging from 37,850 liters to 378,500 liters (10,000 to 100,000 gallons) a day, capital costs can range from $60,000 to $112,500.

Annual operating costs in 1973 dollars of the treatment system for a dry charge plant vary from $5,000 to $38,000 corresponding to 37,850 liters (10,000 gallons) to 3,785,000 liters (1 million gallons) of effluent a day. Operating costs for a wet charge plant range from $5,000 to $6,000 according to effluent ranging from 37,850 liters (10,000 gallons) to 378,500 liters (100,000 gallons) a day.

The basis for these costs is summarized in Table 51.

Table 51. Lead-Acid Battery Waterborne Waste Treatment Cost Estimates (1973 $) — Capital Costs

Capacity (MGD)	Filtration Unit	Lime Storage % Feed	Clarifier	Total
0.1	30,000	30,000-50,000	32,500	112,500
1.0	100,000	50,000-75,000	85,000	260,000
10.0	900,000	75,000-100,000	325,000	1,350,000

			Major Operating Costs	
Capacity Batt/Day	MGD	Capacity Cost (1973 $)	Filtration Unit Capacity (MGD)	Operating Cost/Year (1973 $)
Dry charge 1,430	0.1	112,500	1.0	38,000
Dry charge 14,300	1.0	260,000	10.0	199,000
Wet charge 5,000	0.1	112,500		

The character of the waste sludge from a lead acid battery plant is determined largely by the type of water treatment used. Relatively large volume sludges are produced from lime treatment, containing approximately 0.01% lead. Caustic treatment produces a more concentrated sludge of low volume containing approximately 58% lead. In this industry many plants do not remove lead from their wastewater at the present time due to either meeting effluent regulations existing in their locality or due to lack of regulation. It is anticipated that in the future more plants will be required to treat their wastewater.

Some plants reclaim the lead from the small volume caustic process. Coagulating agents, if used, decrease the possibility of reclaim. If the sludge from caustic treatment is not reclaimed, it should be deposited in a secured landfill, due to the high lead content. Because of the much smaller concentration of lead in the calcium sulfate sludge obtained from lime treatment an approved landfill should prove environmentally safe. Leaching studies of both types of sludge are necessary. Monitoring of the leachate and runoff should give adequate notice for further safeguards, if needed.

Based upon a total of 202 lead acid battery plants in the U.S., three-fourths of these plants (75%) are currently neutralizing their wastewater effluents and discharging either directly to waterways or to municipal treatment plants. Of the 150 plants using neutralization, it is estimated that 60 plants treat the wastewater to precipitate lead containing sludges which are destined for land disposal. Fourteen of these later plants are using lime treatment to produce a calcium sulfate-lead sludge, while the remainder (46) are using caustic to produce a lead hydroxide-sulfate sludge. The numbers of plants using either lime treatment or caustic treatment is expected to increase dramatically in 1977 and 1983 when the EPA effluent guidelines take effect.

6.2.2 Nickel-Cadmium Battery

There are two land-destined hazardous waste streams from nickel-cadmium battery production; i.e., scrap cells, and sludge from wastewater treatment. These two waste streams are often treated to reclaim the hazardous components. The composition of the sludge is 35% nickel hydroxide and 65% cadmium hydroxide on a dry basis. The sludge is assumed to be 35% solids. The scrap waste stream consists of 12% nickel, 43% cadmium and 45% non-hazardous materials.

The wastewater is treated with caustic soda as a precipitating agent and pumped to a settling basin or pond for final disposal of the sludge. A study concerning the migration of hazardous materials through soil has given preliminary indications that the migration of cadmium hydroxide and nickel hydroxide is minimal in neutral and alkaline soil, due to their extremely low solubilities. Under acidic conditions, however, the metal hydroxides become much more soluble. If the sludge is not treated or reclaimed, secured landfill may be necessary due to the high concentration of hazardous materials.

6.3 Treatment and Disposal in Primary Batteries Manufacture (SIC 3692)

The potentially hazardous wastes destined for land disposal from the manufacture of primary batteries primarily consist of reject or scrap cells. However, in the production of magnesium-carbon and lead-reserve cells, wastewater treatment sludges are produced. At the present time, scrap cell wastes are disposed of in landfills. The water treatment sludges are either sold or land disposed. However, as shown in Table 50, there are no hazardous wastes from the manufacture of magnesium-reserve cells and the hazardous wastes from the zinc-silver oxide cell are sold for reclaim value.

The potentially hazardous wastes from this segment of the industry are generally characterized as having a concentrated hazardous waste in a relatively small volume of total waste stream. Where reclaimation of these wastes is not practicable, disposal in a controlled landfill is considered to be an environmentally adequate technology.

The industry at present disposes of these wastes to general landfills. A short study of heavy metal migration from one of these landfills was recently completed. The area investigated was a surface disposal site on the side of a hill, with the lower edge of the landfill approximately 6 meters (20 feet) above a spring-fed streamlet. The disposed material was piled upon the side of the hill, while maintaining a flat top surface. Fill material consisted of crushed batteries and battery components, miscellaneous packaging wastes,and small amounts of spent carbon. The hazardous constituents in the waste were mercury, cadmium, lead,and zinc present roughly in the ratios of 1:1:1:1000. No cover material was used, and between rainstorms the surface was dry and powdery. The streamlet received all rainwater runoff from the disposal site, while the flat surface permitted saturation of the waste during periods of rainfall.

Visual observation showed that nearby vegetative patterns evidenced the presence of toxic materials. Vegetative cover was sparce and scattered within a 15 meters (50 foot) radius. Much of the area was completely bare while slightly raised areas supported some vegetation. Even vegetation in the nearby stream bed appeared to be affected.

The study involved analyzing water and soil samples collected along transects radiating from a central point in the disposal site, and covered about 20% of the disposal area. Soil samples were collected from cores drilled along these transects, 15 (50), 30 (100), and 45 (150) meters (feet) from the central point. Soil from each core was analyzed at 0.3 meters (1 foot)below surface and at 1.5 meters (5 feet) increments until 10.7 meters (35 feet) or bedrock was reached. Soil samples were also obtained in this manner from the center of the disposal area and from sampling sites above the disposal area. Core samples were not collected in or near the stream bed. The bore holes were sometimes capped and used to collect water seeping through the soil immediately after rainstorms. Water samples were collected from the streamlet and the larger stream into which it emptied. Stream sediment was sampled at a point just above the landfill area, 45 meters (150 feet) downstream and from the landfill, and at other points furhter downstream. However, no surface soil samples were collected; no stream sediment samples were taken in the immediate vicinity of the landfill, and no direct rainwater runoff samples were collected.

The results of the study indicated vertical migration of the hazardous metals within the landfill. The concentrations of metals within the site ranged from 200 to 700 ppm Hg, 1,000 to 60,000 ppm Zn, 46 ppm Cd and 12 to 60 ppm Pb. The concentrations of metals in other soil samples, not taken directly in the landfill, varied with depth or distance from the landfill. These concentrations were lower and ranged from 0.1 to 0.9 ppm Hg and 30 to 80 ppm Zn. However, one sample collected at the primary rainfall runoff point 0.3 meter (1 foot) below the surface, contained 3.6 ppm Hg and 1300 ppm Zn.

Streamlet sediment analysis showed an average of 1.4 ppm Hg, 1400 ppm Zn, 3 ppm Cd, and 80-320 ppm Pb; these concentrations varied little with distance from the landfill. The receiving stream sediment showed some evidence of upstream contamination (0.5 ppm Hg, 64 ppm Zn) which may be explained by the levels found in an upstream reservoir sediment sample (1000 ppm Zn).

The concentration of hazardous metals in water sampled showed levels much lower than that for soil and stream sediment samples. In the test holes, concentrations ranged from 0.2 to 10 ppb Hg and 2 to 30 ppm Zn, however, a higher concentration of mercury (38 ppb) was found in the sample from the rainwater runoff pathway. The streamlet water samples ranged from below 0.2 to 0.4 ppb Hg and from below 0.1 ppm to 0.4 ppm Zn in the area downstream from the landfill. Near the landfill, heavy metal concentrations ranged from below 0.2 ppb to 1 ppb Hg and from 2 to 20 ppm Zn.

These results show evidence that migration has occurred of mercury, zinc, cadmium, and lead from the disposal site, vertically towards the bedrock and horizontally to the receiving stream. The results also show evidence that migration of these constituents from stream sediment in the landfill area may have occurred to the larger receiving streams. It is felt that further study of the landfill is warranted to determine the full environmental effects, but the preliminary conclusions are that this type of disposal is environmentally inadequate.

The following sections describe waste practices currently with the industry.

6.3.1 Carbon-Zinc Battery

This cell is produced in 15 plants and constitutes the largest quantity of any primary cell manufactured in the U.S. Its hazardous wastes to land are scrap and reject cells. The amount of waste is estimated to be about 1% of production for a typical plant. It is estimated that the waste stream contains 19% zinc, 2.5%ZnCl, 1% Hg, and smaller amounts of lead and cadmium.

The wastes currently are sent to a simple landfill, either private or municipal. The successful implementation of a disassembly and recovery process would reduce significantly the hazardous materials presently going to landfill from this category.

6.3.2 Alkaline Manganese Battery

This cell is produced in seven plants and constitutes the second largest quantity of any primary cell manufactured in the United States. Hazardous wastes to land consist entirely of scrap and reject cells. The waste is estimated to be about 1% of production for a typical plant. The waste contains about 1% mercury and 16% zinc. The wastes currently are sent to a simple landfill.

6.3.3 Air Cell

This is a specialty battery produced in only three plants. Its hazardous wastes to land consist entirely of scrap and reject cells containing 0.1% mercury and 30% zinc. A 1% waste to production ratio was assumed for a typical plant. The wastes currently are sent to a simple landfill.

6.3.4 Magnesium Carbon

This battery is produced in three plants primarily for military use. It is unique in that no hazardous materials are contained in its reject cells. However, trivalent chromium sludge is produced from water treatment. The sludge from one plant is currently sold to a brick manufacturer.

6.3.5 Mercury Ruben Cell

This battery is produced in seven plants. Hazardous waste from the production from this cell consists of scrap and rejected cells. In the great majority of cases this waste is reclaimed by smelting. Reclaiming is done either by the plant or by a private contractor. The final waste going to simple landfill is slag from the reclaim furnace. This is estimated to contain 1% Hg 56% Zn, and the remainder iron.

6.3.6 Lead Acid Reserve

This battery is produced in only two plants for military usage. The lead-fluoboric acid reserve cell wastes are scrap cells and scrap metals. Hazardous materials in the scrap are estimated to be 55% Pb and 31% Ni. Future water quality standards will probably result in a sludge from water treatment. The sludge is estimated to be 26%

$Pb(OH)_2$ and 74% $Ni(OH)_2$ (dry basis). At present, one plant is in the planning stages of a water treatment process, but no plant as yet is utilizing one. The largest volume of waste is scrap metals from battery production (30% of product) which are sent to simple landfill.

6.3.7 Mercury Weston Cell

This is a limited production cell produced in only one plant. Its wastes are assembled reject batteries. Hazardous materials in the waste are estimated to be 18.5% Hg, 6.2% $HgSO_4$, 7.9% $CaSO_4$, and 4.4% Cd. Present disposal practice is indefinite on-site storage. The assembled cells are completely encased which reduces their hazardousness while in storage.

6.4 Treatment and Disposal Technology Levels as Applied to Hazardous Wastes From The Manufacture of Specific Batteries

The levels of treatment and disposal technology are characterized as follows:

Level I — Technology Currently Employed by Typical Facilities; i.e., broad average present treatment and disposal practice.

Level II — Best Technology Currently Employed. Identified technology at this level must represent the best process from an environmental and health health standpoint, currently in use in at least one (1) location. Installations must be commercial scale; pilot and bench scale installations are not suitable.

Level III — Technology Necessary To Provide Adequate Health and Environmental Protection. Level III technology may be more or less sophisticated or may be identical with Level I or II technology. At this level, identified technology may include pilot or bench scale processes providing the exact stage of development is identified.

These levels of treatment and disposal technology are described in the following series of tables, together with a number of factors which assist in evaluating these technologies. A short description of these evaluation factors follow:

(a) Physical and Chemical Properties of the Waste.
This gives a brief description of the form of this waste and identifies the main constituents.

(b) Amount of Waste (kg per kkg of product).
This factor gives an average quantity or range of the magnitude of the total waste stream treated based upon a waste factor relating the quantity of waste (kilograms) to the quantity of production (metric tons).

(c) Factors Affecting Hazardousness of the Waste.
This gives a brief description of the possible interaction of the surrounding environment with the waste.

(d) Treatment and Disposal Technology.
A description of the type of technology or disposal practice used to handle the hazardous waste.

(e) Number of Plants Now Using This Technology and Percentage.
This is an estimate of the usage of the technology by the number and percentage of plants in the industry.

(f) Adequancy of Technology.
This factor describes the adequacy of the technology with respect to environmental consideration and local regulations.

(g) Problem Areas or Comments.
This gives a brief description of problem areas encountered with the technology or comments.

(h) Non-land Environmental Impact.
This describes the possible impact of the technology to non-land environmental factors such as water or air quality.

(i) Compatibility with Existing Facilities.
This factor describes whether the technology can be used by existing plants or waste disposal contractors.

(i) Monitoring and Surveillance.
This describes the type and frequency of monitoring necessary for the technology.

(k) Energy Requirements.
This factor describes the qualitative amount of energy requirements for the technology.

6.4.1 SIC 3691, Storage Batteries Treatment and Disposal Technology Levels

The following Tables 51 through 53 provide information on the three identified and contractor recommended levels of treatment and disposal of hazardous wastes from the storage batteries industry.

6.4.2 SIC 3692, Primary Batteries Treatment and Disposal Technology Levels

Tables 54 through 58 provide information on the three identified and contractor recommended levels of treatment and disposal of hazardous wastes from the primary batteries industry.

6.5 General Treatment Technologies

Treatment technologies applicable to the battery industry are discussed in the following sections along with other technologies spelled out to be investigated under this study.

6.5.1 Chemical Detoxification

Toxic or hazardous wastes are often treated chemically to reduce or destroy their hazardous nature. These treatments most often are included in water quality maintenance, but can be utilized for land-destined wastes as well, particularly by off-site contractors. One example of chemical detoxification of a hazardous waste from the battery industry was the reduction of hexavalent chromium trioxide to trivalent chromium hydroxy-carbonate.

6.5.2 Neutralization

Acid wastes from lead acid battery production are reacted with caustic to form neutral salts. The resulting salts are less hazardous than either of the reactants. Also, the resultant salt may be insoluble and precipitate from the solution. Calcium salts derived from low cost limestone or lime are particular examples of limited solubility. The reactions shown under Section 6.5.4 are also neutralization reactions.

6.5.3 pH Control

The control of pH may be equivalent to neutralization if the control point is at or close to pH 7. Sometimes chemical addition to waste streams is designed, however, to maintain a pH level on either the acidic or basic side for purposes of controlling desired reactions or solubility. The pH of effluent of the wastewater treatment from lead-acid storage battery production is maintained at around pH 9, to minimize $PbSO_4$ solubility.

Table 51. Treatment and Disposal Technology for Sludge From Lead Acid Battery Production

Factor	Level I, Prevalent Technology	Level II, Best Available Technology	Level III, Adequate Health and Environmental Protection
Physical and Chemical Properties of Waste	(1) Sludge containing $PbSO_4$ and $Pb(OH)_2$ (80% solids) or (2) Sludge containing $CaSO_4$ (35% solids) and 150 ppm lead.	Same as Level I	Same as Level I
Amount of Waste (kg per kkg of product)	(1) 0.5 (2) 2,100	(1) 0.5 (2) 2,100	(1) 0.5 (2) 2,100
Factors Affecting Hazardousness of Waste	Acidic conditions of land storage may cause leaching of lead.	Same as Level I	Same as Level I
Treatment and Disposal Technology	Land storage of sludge.	(1) Land storage of sludge with leachate collection and treatment. (2) Return lead hydroxide sludge to smelter for reclaim.	(1) Deposit calcium sulfate sludge in approved landfill. (2) Chemical fixation of sludge, and simple landfill, (pilot stage). (3) Disposal of lead hydroxide sludge in secured landfill.
Number of Plants Now Using Technology (%)	60 (30%) Land storage for sludge. 90 (45%) Neutralization and discharge, no sludge generated. 50 (25%) No wastewater treatment, no sludge.	(1) 1 (0.5%) (2) 2 (1%)	(1) (0) (2) (0) (3) (0)
Adequacy of Technology	Inadequate sludge disposal, possible migration of wastes.	(1) Inadequate due to lack of leachate and runoff monitoring. (2) Adequate, however, lead cannot be reclaimed if impurities are present.	(1) Adequate (2) Adequacy not yet fully determined. (3) Adequate
Problem Areas and Comments	Possible leaching of lead in landfill to watertable or stream.	(1) No leachate monitoring. (2) Future water quality standards may require use of flocculants, making recovery impossible.	(1) Should monitoring indicate significant leaching, further steps may be necessary. (2) Fixed sludge may be suitable for construction purposes. (3) Existence and location.
Non-land Environmental Impact	Possible leaching to watertable.	(1) Possible runoff. (2) None.	(1) None apparent. (2) None apparent. (3) None apparent.
Compatability with Existing Facilities	Good, presently in use.	(1) Good. Land is the only limiting factor. (2) Good	(1) Good; land and location are limiting factors. (2) Good; if facilities exist. (3) Good; land and location are limiting factors.
Monitoring and Surveillance	Little or none in use.	(1) Little or none in use. (2) None required.	(1) Monitoring wells and runoff surveillance. (2) Leachate surveillance. (3) Monitoring wells.
Energy Requirements	Small, land storage operation.	(1) Small, land storage operation. (2) Small, transportation.	(1) Same as Level II-1. (2) Same as Level II-1. (3) Same as Level II.

Table 52. Treatment and Disposal Technology for Scrap Cells From Production of Nickel-Cadmium Batteries

Factor	Level I, Prevalent Technology	Level II, Best Available Technology	Level III, Adequate Health and Environmental Protection
Physical and Chemical Properties of Waste	12% Ni, 43% Cad, 45% non-hazardous materials in form of scrap cells.	Same as Level I.	Same as Level I.
Amount of Waste (kg per kkg of product)	12	12	12
Factors Affecting Hazardousness of Waste	High levels of nickel and cadmium which could leach under acidic conditions.	Same as Level I.	Same as Level I.
Treatment and Disposal Technology	Simple landfill.	Sale to scrap reclaim firms.	(1) Same as Level II. (2) Secured landfill.
Number of Plants Now Using Technology (%)	2 (20%)	8 (80%)	(1) 8 (80%) (2) 0
Adequacy of Technology	Inadequate, possible migration of hazardous materials	Adequate, however, subject to demand and price of scrap.	(1) Adequate, same as Level II. (2) Adequate, secured landfill not only eliminates possible migration of materials, but provides a permanent record of their burial.
Problem Areas and Comments	Possible migration into watertable.	The elimination of landfilling this waste is an obvious benefit.	(1) Same as Level II. (2) Existence and location.
Non-land Environmental Impact	Possible migration of hazardous materials to watertable.	Undetermined.	(1) Undetermined. (2) None.
Compatability With Existing Facilities	Good	Good	(1) Good. (2) Good; transportation and availability of secured landfill are limiting factors.
Monitoring and Surveillance	None reported.	Not applicable.	(1) Not applicable. (2) Monitoring wells.
Energy Requirements	Small, landfill operations.	Small.	(1) Same as Level II. (2) Small, transportation.

Table 53. Treatment and Disposal Technology for Water Treatment Sludge From Production of Nickel-Cadmium

Factor	Level I, Prevalent Technology	Level II, Best Available Technology	Level III, Adequate Health and Environmental Protection
Physical and Chemical Properties of Waste	Sludge 35% solids composed of 35% $Ni(OH)_2$ and 65% $Cd(OH)_2$ (dry basis).	Same as Level I.	Same as Level I.
Amount of Waste (kg per kkg of product)	20	20	20
Factors Affecting Hazardousness of Waste	High levels of hazardous metal hydroxides. Solubility of these under acidic conditions could cause leaching.	Same as Level I.	Same as Level I.
Treatment and Disposal Technology	Land storage.	Sale to scrap reclaim firms.	(1) Same as Level II. (2) Secured landfill. (3) Chemical fixation of sludge and simple landfill.
Number of Plants Now Using Technology (%)	1 (10%)	9 (90%)	(1) 9 (90%) (2) 0 (0%) (3) 0 (0%)
Adequacy of Technology	Inadequate.	Adequate, however, subject to demand and price for scrap.	(1) Adequate. (2) Adequate. (3) Adequate not yet fully determined.
Problem Areas and Comments	Possible migration of hazardous metals.	Reclaimation is desirable.	(1) Same as Level II. (2) Availability. (3) Several undetermined factors.
Non-land Environmental Impact	Possible migration of hazardous materials to watertable.	Undetermined.	(1) Same as Level II. (2) None (3) Undetermined.
Compatability with Existing Facilities	Good	Good	(1) Good. (2) Good, transportation and availability of sites are limiting factors. (3) Good.
Monitoring and Surveillance	None reported.	Not applicable.	(1) Not applicable. (2) Monitoring wells. (3) Leachate surveillance.
Energy Requirements	Small, pumps.	Small.	(1) Same as Level II. (2) Small, transportation. (3) Small, pumps and mixers.

Table 54. Treatment and Disposal Technology for Carbon-Zinc, Air and Alkaline Rejected Cells

Factor	Level I, Prevalent Technology	Level II, Best Available Technology	Level III, Adequate Health and Environmental Protection
Physical and Chemical Properties of Waste	Carbon-Zinc - 730 ppm Hg, 27 ppm Cd, 31 ppm Pb; 19.0% Zn, 2.48% $ZnCl_2$. Alkaline - 750 ppm Hg; 16.2% Zn. Air - 117 ppm Hg; 24.9% Zn.	Same as Level I.	Same as Level I.
Amount of Waste (kg per kkg of product)	1.0	Same as Level I.	Same as Level I.
Factors Affecting Hazardousness of Waste	High levels of mercury zinc, cadmium, and lead. These metals could leach under acidic conditions.	Same as Level I.	Same as Level I.
Treatment and Disposal Technology	Simple landfill with few or no safeguards.	Private landfill for hazardous wastes. Leachate surveillance.	(1) Secured landfill. (2) Recovery of zinc, mercury, cadmium, and lead (pilot stage).
Number of Plants Now Using Technology (%)	24 (96%)	1 (4%)	(1) 0 (0%) (2) 0 (0%)
Adequacy of Technology	Inadequate, due to possible migration of hazardous materials.	Adequate, but not as good as Level III technology.	(1) Adequate. (2) Adequate.
Problem Areas and Comments	Possibility of migration of hazardous materials.	Same as Level I.	(1) Existence and availability of sites. (2) Undetermined.
Non-land Environmental Impact	Possible watertable contamination.	Possible watertable contamination.	(1) None (2) Undetermined.
Compatability with Existing Facilities	Good.	Good.	(1) Good, transportation and availability of sites are determining factors. (2) Undetermined.
Monitoring and Surveillance	None	Leachate surveillance.	(1) Monitoring wells. (2) Not applicable.
Energy Requirements	Small, landfill operations.	Small, transportation.	(1) Small, transportation. (2) Undetermined.

Table 55. Treatment and Disposal Technology for the Mercury Cell

Factor	Level I, Prevalent Technology	Level II, Best Available Technology	Level III, Adequate Health and Environmental Protection
Physical and Chemical Properties of Waste	Slag from reclaim furnnce - 1% Hg, 56% Zn, 43% non-hazardous.	Same as Level I.	Same as Level I.
Amount of Waste (kg per kkg of product)	8	Same as Level I.	Same as Level I.
Factors Affecting Hazardousness of Waste	Mercury and zinc content.	Same as Level I.	Same as Level I.
Treatment and Disposal Technology	Mercury reprocessing on-site or sale to reprocessor. Simple landfill of slag.	Same as Level I.	Mercury reprocessing with secured landfill of slag.
Number of Plants Now Using Technology (%)	7 (100%)	Same as Level I.	0 (0%)
Adequacy of Technology	Inadequate, because although migration of materials is not known, future leaching is possible.	Same as Level I.	Adequate.
Problem Areas and Comments	Reclaiming is sometimes done by outside reprocessor.	Same as Level I.	Same as Level I.
Non-land Environmental Impact	Possible leaching.	Same as Level I.	None apparent.
Compatability With Existing Facilities	Already being done.	Same as Level I.	Existence and availability of sites.
Monitoring and Surveillance	None in use.	Same as Level I.	Monitoring wells.
Energy Requirements	Minimal, transportation and fuel for furnace.	Same as Level I.	Same as Level I.

Table 56. Treatment and Disposal Technology for the Mercury Weston Cell

Factor	Level I, Prevalent Technology	Level II, Best Available Technology	Level III, Adequate Health and Environmental Protection
Physical and Chemical Properties of Waste	Scrap batteries containing - 18.5% Hg, 4.4% $CdSO_4$, 5.3% $HgSO_4$, 3.6% Cd and 66.8% non-hazardous materials.	Same as Level I.	Same as Level I.
Amount of Waste (kg per kkg of product)	10	Same as Level I.	Same as Level I.
Factors Affecting Hazardousness of Waste	Toxic materials in containers.	Same as Level I.	Same as Level I.
Treatment and Disposal Technology	Indefinite storage.	Indefinite storage.	Disposal in secured landfill.
Number of Plants Now Using Technology (%)	1 (100%)	1 (100%)	0 (0%)
Adequacy of Technology	Adequate presently, however, must be disposed of eventually.	Same as Level I.	Adequate.
Problem Areas and Comments	Stored wastes must eventually be disposed of.	Same as Level I.	The limited production of this cell lends some latitude toward its disposal.
Non-land Environmental Impact	None	None	None
Compatability With Existing Facilities	Good	Good	Existence and availability of sites.
Monitoring and Surveillance	None	None	Monitoring wells provided.
Energy Requirements	None	None	Minimal.

Table 57. Treatment and Disposal Technology for Magnesium Carbon Cell Sludge

Factor	Level I, Prevalent Technology	Level II, Best Available Technology	Level III, Adequate Health and Environmental Protection
Physical and Chemical Properties of Waste	Sludge (50% solids) chromium hydroxy-carbonate.	Same as Level I.	Same as Level I.
Amount of Waste (kg per kkg of product)	27.6	27.6	27.6
Factors Affecting Hazardousness of Waste	Precipitated chromium could be solubilized in acidic environment.	Same as Level I.	Same as Level I.
Treatment and Disposal Technology	Simple landfill.	Sale of sludge for production of non-clay refractories.	(1) Chemical fixation and simple landfill. (2) Secured landfill.
Number of Plants Now Using Technology (%)	2 (67%)	1 (33%)	(1) 0 (0%) (2) 0 (0%)
Adequacy of Technology	Inadequate, possible leaching.	Adequate, however, subject to demand.	(1) Adequacy not fully determined. (2) Adequate.
Problem Areas and Comments	Possible leaching.	Subject to demand.	(1) Availability. (2) Existence and availability.
Non-land Environmental Impact	Possible leaching.	None	(1) Undetermined. (2) None.
Compatability With Existing Facilities	Good	Fair	(1) Good (2) Good, transportation and availability are factors.
Monitoring and Surveillance	None in use.	Not needed.	(1) Leachate surveillance. (2) Monitoring wells provided.
Energy Requirements	Minimal	Small	Same as Level I.

Table 58. Treatment and Disposal Technology for Lead-Fluoboric Acid Reserve Cell (Scrap and Sludges)

Factor	Level I, Prevalent Technology	Level II, Best Available Technology	Level III, Adequate Health and Environmental Protection
Physical and Chemical Properties of Waste	Scrap and scrap cells - 55% Pb, 31% Ni, 14% non-hazardous materials. Sludge (35% solids)- 26% $Pb(OH)_2$ and 74% $Ni(OH)_2$ (dry basis): Future wastewater treatment basis.	Same as Level I.	Same as Level I.
Amount of Waste (kg per kkg of product)	Scrap - 330; sludge - 8.2.	Same as Level I.	Same as Level I.
Factors Affecting Hazardousness of Waste	High levels of Ni and Pb.	Same as Level I.	Same as Level I.
Treatment and Disposal Technology	Simple landfill of scrap.	Same as Level I.	Secured landfill of scrap and sludge.
Number of Plants Now Using Technology (%)	2 (100%)	2 (100%)	0
Adequacy of Technology	Inadequate, possible migration of hazardous materials.	Same as Level I.	Adequate.
Problem Areas and Comments	Much of the scrap generated might be eliminated by recycle.	Same as Level I.	Existence and availability of sites.
Non-land environmental Impact	Possible leaching.	Same as Level I.	None.
Compatability With Existing Facilities	Good, in practice.	Same as Level I.	Good, transportation and availability of landfill are limiting factors.
Monitoring and Surveillance	None in use.	Same as Level I.	Monitoring wells.
Energy Requirements	Minimal, fuel for equipment.	Same as Level I.	Small, transportation to landfill site.

6.5.4 Precipitation

This reaction is the basis of eliminating many undesirable water-borne wastes from a waste stream. The use of the technique in the battery industry is predominantly limited to the production of storage batteries. Lime or caustic which are used to neutralize the acidic wastewater, also cause the lead, nickel,or other active ingredients to precipitate out of solution. The result is a sludge of high water content. The suspended solids may be further removed by the use of settling basins, clarifiers, or thickeners.

The following are examples of precipitation reactions used for wastewater treatment in the storage batteries industry.

(1) $Ca(OH)_2 + PbSO_4 = CaSO_4\downarrow + Pb(OH)_2\downarrow$

(2) $2NaOH + PbSO_4 = Na_2SO_4 + Pb(OH)_2\downarrow$

(3) $2NaOH + NiSO_4 = Na_2SO_4 + Ni(OH)_2\downarrow$

(4) $2NaOH + CdSO_4 = Na_2SO_4 + Cd(OH)_2$

The addition of the above caustic chemicals also results in the neutralization of pH control of the acid streams, as shown below:

(1) $Ca(OH)_2 + H_2SO_4 = CaSO_4 \cdot 2H_2O\downarrow$

(2) $2NaOH + H_2SO_4 = Na_2SO_4 + 2H_2O$

6.5.5 Recovery and Reuse

Many toxic or hazardous storage battery wastes contain valuable materials. Whenever this is the case, recovery and reuse is one of the most desirable methods of pollution avoidance. Lead, nickel,and other heavy metals, once they are removed from water or air streams, are sometimes recovered economically rather than land disposed. Only when these metals are very minor constituents of the waste is it not economical to follow the recovery or reuse approach (as in calcium sulfate sludge). Therefore, most heavy metal land-disposed wastes from the storage batteries industry are so diluted that their hazardousness is greatly reduced. Primary rejected batteries are a likely prospect for recovery from battery industry wastes. The major factor standing in the way of recovery of most of the heavy metals going to landfill in this category is the disassembly of the cells to separate the recoverable and non-recoverable components. Until now it has not been economically feasible to disassemble the cells. The rising costs of raw materials, however, may soon change this situation.

A pilot program in one major battery company indicates that it is economically favorable to recover a majority of the hazardous wastes through disassembly.

There are also private contractors that specialize in hazardous waste reclamation. In the battery industry this situation is encountered in reject mercury cells, silver cells, and cadmium cells.

6.5.6 Burning and Incineration

Since battery industry wastes are generally non-combustible and their wastes are mainly found as sludges and liquids, or reject cells, burning or incineration is not used for treatment or disposal of wastes.

6.5.7 High Temperature Processing

Although not flammable, battery wastes in some cases can be smelted in a fashion similar to recovery of metals from ores. Mercury can be driven from wastes by heating in furnaces and retorts, condensed in chilled heat exchangers, and recovered.(24)

Smelting operations are also widely used for lead wastes recovered from the production of lead acid storage batteries.

6.5.8 Open Dumping

Open dumping of hazardous battery wastes into gravel pits, dumps, and other uncontrolled disposal areas is still a prevalent disposal practice. Most of the companies producing batteries contacted, however, have demonstrated increasing awareness and responsibility for treatment, control, and disposal of hazardous wastes. According to information from both private contractors and interviewed battery producers, most companies want no "surprises" from disposal and are checking closely on both their own and contract disposal sites and procedures.

Massive calcium sulfate sludges are the major wastes from the storage batteries industry. These large volume wastes, containing relatively small amounts of hazardous components, are currently land stored or landfilled. The large volume and the obvious economic impact of more costly treatment and disposal technology makes it necessary to consider the alternative technologies carefully.

6.5.9 Municipal Sewers

Hazardous wastes from a number of battery plants currently go into municipal sewer systems. These materials wind up in sewage sludge, some of which is destined for land disposal, or in the effluent from the treatment plant. The amount of hazardous waste being discharged to sewers varies with the amount removed by water treatment methods. It is anticipated that a lesser amount of hazardous wastes will be discharged to sewers in the future.

6.5.10 Burial Operations

Major quantities of battery industry hazardous wastes go into burial operations. These wastes include dry solids and sludges. Burial locations include both public and private landfills.

6.5.11 Public and Private Landfills

Landfill operations are the preferred method of disposing of hazardous non-flammable solids and sludges. The prime requisite for such disposal is that the hazardous contents of the landfill be isolated from the surrounding environment. Water quality of surface and ground water must not be compromised. Air quality must also be maintained. A more detailed discussion of landfills is given in a later section.

6.5.12 Disposal Ponds or Lagoons

Disposal ponds or lagoons provide a simple and economic approach to on-site hazardous waste disposal, where applicable. However, there are some serious drawbacks.

(a) The pond must provide protection from both surface and groundwater contamination. In almost all areas this means a lined pond. Liners include clay, plastic, concrete,and epoxy, all of which are relatively expensive.

(b) Except in very dry climates, ponds without discharge will overflow from rainfall accumulation.

(c) Ponds are prone to be "flushed out" with massive rainfall. It is difficult and expensive to provide flood protection.

In the battery industry, ponding was only rarely encountered for sludge from water treatment.

6.5.13 Deep Well Injection

Deep welling is a specialized form of land disposal of hazardous wastes. It is normally restricted to liquids only since suspended solids or sludges tend to clog the porous rock shale on sand structure into which the injection occurs. Since battery wastes are almost exclusively solids or sludges, deep welling is not a viable alternative.

6.5.14 Ocean Barging

Currently a number of hazardous wastes generated by industry are disposed of by ocean barging. Some of these wastes will in the future be destined for land disposal. This method is not presently used by the batteries industries, and because of possible environmental damage is not a good choice for future disposal.

6.6 Land Disposal Practices

6.6.1 Landfill Types

Landfills may be classified as:

(a) General purpose landfills;
(b) Approved landfills – for hazardous wastes;
(c) Secured landfill operations for extremely hazardous wastes.

6.6.1.1 General Purpose Landfills

It is estimated that 85% of the land-destined hazardous waste from the battery industry currently finds its way into general purpose landfill sites. General purpose landfills are characterized by their acceptance of a wide variety of wastes, including organic materials, and by the usual absence of special containment, monitoring, and leachate treatment provisions for hazardous wastes.

The potential for environment damage by landfilled hazardous wastes differs depending on both the composition and quantity of that waste. Many general purpose landfills will accept small quantities of hazardous wastes, particularly if they are in drums or plastic containers, but refuse large amounts.

When the hazardousness level is relatively low, due either to the inherent characteristic of the compound or its low concentration in the overall waste mass, even large quantities of hazardous wastes may be accepted.

6.6.1.2 Approved Landfills

Each general purpose landfill has its own ambience — geologically, hydrologically, and environmentally. Ideally, a general purpose landfill would be located in an isolated, dry part of the country with a thick layer of impermeable soil between the waste and the water table. Such areas are plentiful in the western part of the U.S., but not in the east. However, many existing and future landfill sites throughout the U.S. can approach ideal conditions.

The degree of approach is differentiated in this report as approved landfills and secured landfills. Secured landfills are defined and discussed in a following section.

Approved landfills are defined to meet the following criteria:

(a) The composition and volume of each hazardous waste is known and approved for site disposal by pertinent regulatory agencies.

(b) The site should be ambiently suitable for hazardous wastes.

(c) Provision is made for monitoring wells, rain water diversion, and leachate control and treatment, if required.

The advantages of approved landfill sites include:

(a) Many hazardous wastes may be disposed of in a controlled and environmentally safe fashion.

(b) Selection of landfill sites and disposal technology for ambience suitability still leaves a great number of available landfill sites.

(c) Disposal costs, for both transporting the waste to the site and the landfilling itself, are kept to levels close to those for general purpose sites and still much lower than for secured landfill.

From a practical standpoint many local regulatory agencies and landfill site owners are informally practicing much of this discrimination by selective acceptance of waste materials. Sites with known high potential for surface and ground water contamination are thereby avoided. Battery wastes are rarely disposed of in approved landfills at the present time.

6.6.1.3 Approved Landfill for Large Volume Hazardous Wastes

Large volume hazardous wastes normally have their own landfill site so that interaction with other wastes is not a factor. Also, since transportation costs are high, disposal is usually either on-site or within a few miles of the plant.

6.6.1.4 Secured Landfills

The battery industry has a number of small volume wastes of hazardous potential. For these wastes landfilling involves additional safeguards beyond those described for approved landfills. Criteria for these secured landfills include:

(a) The composition and volume of each extremely hazardous waste is known and approved for site disposal by pertinent regulatory agencies.

(b) The site should be geologically and hydrologically approved for extremely hazardous wastes. Included in the criteria would be a soil or soil/liner permeation rate of less than 10^{-7} cm per sec, a water table well below the lowest level of the landfill, and adequate provision for diversion and control of surface water.

(c) Monitoring wells are provided.

(d) Leachate control and treatment (if required).

(e) Records of burial coordinates to avoid any chemical interactions.

(f) Registration of site for a permanent record once filled.

No instance of a battery company utilizing a secured landfill for its wastes was found.

A number of landfills which meet the physical requirements (if not all the regulatory criteria) are located around the country. California has a number of Class I impermeable landfills which accept extremely hazardous materials. Texas has similar sites. A number of low level-radioactive waste landfill sites accept industrial hazardous wastes. In addition to the radioactive waste sites various other private secured landfills also take extremely hazardous wastes. At the present time secured landfills are scattered and not fully utilized. Part of the lack of utilization stems from the fact that the majority of the sites are in isolated western areas away from industrial centers. Another reason for the lack of utilization is the high cost as compared to other available disposal methods.

Relatively isolated impermeable soil conditions exist in many areas of the country. If impermeable soil is not available then clay, special concrete, asphalt, plastic and other liners and covers are available to accomplish similar containment and isolation of wastes.

6.6.2 Safeguard Practices

6.6.2.1 Direct Plastic/Concrete Encapsulation

Direct hazardous wastes encapsulation in concrete is now practiced by at least one contract disposer. The practice is used for small quantities of containerized miscellaneous hazardous wastes.

6.6.2.2 Steel Drums

Steel drums, alone or with plastic liners, not only provide some long-term containment but also are the most convenient storage and transportation mode for relatively small quantities of wastes. The ultimate problem involved is the eventual decay of the steel drums. Therefore, unless disposed of in an appropriate landfill site, future release to the environment is likely.

6.6.2.3 Clay or Asphalt Encapsulation in Bulk

In wet climates, sections of or entire landfill areas are encapsulated by adding clay or asphalt "caps" or "covers" to impervious isolation cells or landfill liners.

The impervious cover is necessary to protect the hazardous waste from rainfall flooding. Neutralizing or pH control ingredients such as lime may also be used to encase or surround the hazardous waste to avoid solubility, decomposition or other change in the character of the waste to increase its environmental damage.(25,26)

In dry climates, there is no need to encapsulate the entire landfill since rainfall and water buildup is not a problem. Isolation cells may still be constructed, however, for specific hazardous waste containment.

6.6.2.4 Leachate Collection and Treatment

In wet climates, particularly, both private and public landfills are paying increasing attention to leachate collection, monitoring and treatment. Landfill areas in the State of Pennsylvania are representative of those in a wet climate and leaching treatment has been initiated in some public landfill areas. Leachate monitoring and treatment is also practiced in an on-site storage battery plant landfill. The vast majority of the landfill operations handling hazardous wastes, however, do not have any leachate control and treatment provisions.

6.6.2.5 Chemical Fixation

Hazardous sludges are being increasingly treated either on-site or in collection areas by mixing them with inorganic chemicals and catalysts to set up the entire mass into solid structures with low leachability and good land storage or landfill characteristics. There are a number of such processes which produce solids ranging from crumbly soil-like materials to concrete to ceramic slags.(27,28) There has been no reported instance of chemical fixation being used on battery industry wastes. It is, however, a possibility for sludge treatment in the battery industry.

6.6.2.6 Practical Landfill Disposal Factors

Once a landfill area has been isolated from surface and groundwater contact and leachates are being handled satisfactorily, almost any non-flammable, non-explosive and non-air polluting hazardous waste can theoretically be disposed of safely. There are a number of practical restrictions, however, to this approach:

(a) In wet climates the impervious landfills are flooded with heavy rainfall. Dumping of liquids or sludges into the landfill only accentuates the problem.

(b) Some hazardous wastes create hazards for landfill personnel or give air pollution problems.

(c) Chemical interactions with both other materials and the liner can cause undesirable side effects.

Rainfall:

In the southwestern U.S. The annual rainfall is significantly less than the evaporation. In the San Francisco area a net evaporation rainfall differential of 1.2 meters exists. Therefore, in these dry climates, liquid and sludge hazardous wastes can be mixed into either refuse or fill dirt without having the landfill area flooded.

Chemical Interactions:

Indiscriminate dumping of hazardous chemicals into landfills leads to serious interactions. Acid attacks metallic sulfides and changes the solubility of heavy metal precipitates. In battery wastes, acid and alkaline reject cells must be separated. The heat produced upon neutralization could be enough to ignite some other flammable waste.

In addition to the chemical interactions between landfill components, liners can also be attacked. Many plastic materials used in liners are attacked by organic solvents, oxidizing agents and other waste components. Clay liners are attached by a variety of chemicals and become more porous. An old construction practice is to mix clay with lime to give a sand-like soil. There have been instances in California where clay liners have failed to stop seepage of hazardous wastes such as chromates into ground water.(29) It is believed that chemical impairment of the clay liner was responsible.

6.6.2.7 Coordinate Records

Landfilling of hazardous wastes as discussed earlier in this section can lead to undesirable chemical interactions. A few public and private landfill operations keep records of all hazardous waste burials by location and composition. By means of this record undesirable interactions may be avoided and potentially reactive chemicals isolated from each other. One necessary corollary to coordinate record keeping is prior knowledge of hazardous wastes coming to the landfill area so that a satisfactory disposal section may be selected. Prior written requests for the specific hazardous waste disposal are already required for some public and private landfill areas.

6.6.2.8 Safeguards Presently Used in Disposal

Much of the waste generated by the battery industry is land-dumped or landfilled with little or no safeguards used. In one case an asphalt pad is used along with a leachate collection and treatment system. One plant is encapsulating their wastes in steel drums before burial. Several plant wastes are covered and compacted daily in fenced and attended sites.

In almost all cases, the safeguards in use reflect state efforts to regulate landfill techniques.

6.6.2.9 On-Site vs. Off-Site Disposal

On the basis of information from approximately 30 companies, involving 72 plant sites, approximately 80% (57 plants) hire contractors or use public facilities for off-site disposal of at least a portion of their hazardous wastes. The remaining 20% treat and dispose of their own wastes. In general, contractors are used for small volume wastes, particularly in congested areas where treatment and disposal land is at a premium. Off-site disposal probably accounts for 65% of the total volume disposed.

6.7 Private Contractors and Service Organizations

Off-site treatment and disposal of land-destined hazardous wastes from the battery industry are sometimes handled by private contractors and waste service organizations. The contractors may provide both hauling and disposal services. A list of private treatment/disposal contractors and waste service organizations is shown in Appendix B. This list is not intended to be complete but does give a good cross-section of involved facilities including most of the largest and most active.

7.0 COST ANALYSIS

Cost information contained in this report was assembled directly from industry, from waste treatment and disposal contractors, engineering firms, equipment suppliers, government sources, and published literature. Whenever possible, costs are based on actual installations, engineering estimates for projected facilities as supplied by contributing companies, or from waste treatment and disposal contractors quoted prices. In the absence of such information, costs estimates have been developed insofar as possible from plant-supplied costs for similar waste treatments and disposal for other plants or industries. Most of the treatment and disposal technology levels and costs developed have been submitted for comment to the specific companies and plants producing the involved products. Adjustments have then been made incorporating these inputs.

The estimates presented were prepared on an engineering basis, using accepted engineering format. No attempt was made to prepare estimates which would reflect impact on individual companies financial statements. Inclusion of tax considerations, product pricing, and other such factors would entail practices unique to each company, and should be recognized as beyond the scope of this report.

7.1 Summary

A cost analysis has been developed for all land-destined hazardous wastes discussed in Section 6.0 for the appropriate treatment and disposal technologies. Tables 59 and 60 summarize the costs for treatment and disposal of the wastes for typical plants producing each type of battery as a function of technology level. "Typical" plants based on weighted average sizes for the industry are used for cost development rather than any specific plant. Costs are also generalized rather than representing those for any specific plant.

Whenever treatment and disposal costs for the waste streams from any typical plant are less than $500 annually, they are reported as such. Disposal for very small amounts of materials generated over a year's production are difficult to estimate meaningfully. Where reclamation may be utilized to eliminate a hazardous waste to landfill, the disposal cost is taken as zero for the reclaiming operation.

Plant age and size are not major factors influencing costs. The controlling factors are the amount and composition of the wastes inherent to the process and the close availability of suitable treatment or disposal sites. Location is a factor in the availability of suitable disposal sites, but its influence is somewhat mitigated by the fact that the vast majority of the battery plants are in the eastern half of the U.S. Transportation costs of wastes to the nearest secured landfill are based on 400 kilometers (250 miles) one way as an estimate. The landfill costs are based on approved or secured sites.

Table 59. Summary of Typical Plant Costs for Treatment and Disposal of Land Destined Hazardous Wastes From Storage Batteries Manufacture (SIC 3691)

Battery Type	1973 Total Industry Production (kkg/yr)	Hazardous Waste Stream	Typical Plant Production (kkg/yr)	Amount of Hazardous Constituents in Typical Plant Waste Stream (Dry Basis) (kkg/yr)	Quantity of Plant Total Waste Stream (Wet Basis) (kkg/yr)	Annual Typical Plant Cost for Treatment and Disposal Technology (Dollars)		
						Level I	Level II	Level III
(a) Lead Acid	1,081,187	(1) Lead containing sludge resulting from lime wastewater treatment	8200	2.6	17,290	26,840	43,110	36,600
		(2) Lead containing sludges resulting from caustic wastewater treatment		2.6	4.46	1,400	< 500	1,000
(b) Nickel-Cadmium	4,005	(1) Sludge from caustic wastewater treatment containing cadmium and nickel hydroxides	447	3.1	8.9	1,950	0	2,450
		(2) Rejected and scrap cells containing cadmium and nickel		3.0	5.4	100	0	500
(c) Cadmium-Silver Oxide	Not Available	(1) Wastewater treatment sludge containing silver oxide and cadmium hydroxide	36.2	0.3	0.5 (reclaimed)	0	0	0
		(2) Rejected and scrap cells containing cadmium and silver oxide		0.3	0.4 (reclaimed)	0	0	0
(d) Zinc-Silver Oxide	Not Available	(1) Rejected and scrap cells containing zinc oxide-hydroxide, silver oxide and mercury	Not Available	Not Available	Not Available (reclaimed)	0	0	0

Table 60. Summary of Typical Plant Costs for Treatment and Disposal of Land Destined Hazardous Wastes From Primary Batteries Manufacture (SIC 3692)

Battery Type	1973 Total Industry Production (kkg/yr)	Hazardous Waste Streams	Typical Plant Production (kkg/yr)	Amount of Hazardous Constituents in Typical Plant Waste Stream (Dry Basis) (kkg/yr)	Quantity of Plant Total Waste Stream (Wet Basis) (kkg/yr)	Annual Typical Plant Cost for Treatment and Disposal (Dollars)		
						Level I	Level II	Level III
(a) Carbon-Zinc	95,900	Rejected and Scrap Cells	2,270	9.2	22.7	2,500	3,020	3,635
(b) Carbon-Zinc Air Cell	Not Available	Rejected and Scrap Cells	1,500	0.45	15.4	2,200	2,660	3,000
(c) Alkaline-Manganese	14,000	Rejected and Scrap Cells	2,000	3.5	20	1,695	2,048	2,310
(d) Mercury	1,845	Scrap Cells and Furnace Residue	450	2.6	3.6	< 500	< 500	1,000
(e) Weston Mercury Cell	0.9	Rejected and Scrap Cells	0.9	0.003	0.009	0	0	< 500
(f) Magnesium Carbon	3,700	Wastewater Effluent Treatment Sludge	1,350	15	37.5	1,400	1,400	4,000
(g) Zinc-Silver Oxide	525	Rejected and Scrap Cells	59.1	0.001	0.59 (reclaimed)	0	0	0
(h) Lead Acid Reserve	Not Available	(1) Scrap and rejected cells (2) Wastewater treatment sludge	45.4	13 0.13	14.9 0.37	2,000	2,000	3,500
(i) Magnesium Reserve	Not Available	None	Not Available	None	Not Available	0	0	0

7.2 Contractor Treatment and Disposal Costs

The costs for contractor handling of hazardous wastes from this industry may be broken down into two basic components — the cost of getting the waste to the treatment and disposal facilities and the treatment and disposal costs themselves. Depending on circumstances, either cost may dominate.

7.2.1 Transportation Costs

Transportation or hauling costs depend on many factors, individualistic with each contractor and waste situation. The most important of these factors include:

(a) Distance
(b) Type of transportation used
(c) Amount of wastes
(d) Region of the country

A constant density factor has been used for all cost calculations since almost all wastes are relatively dense materials.

Almost all hazardous wastes taken from battery plants are transported by trucks. This transportation may be broken down into local hauling and long distance hauling. Local hauling is defined as 80 kilometers (50 miles)(one way) or less.

7.2.1.1 Local Hauling

When distances are short more then one load may be made per day. Loading and unloading times become a major factor. Fast loading by power shovels and loaders and fast unloading by simple dumping, for example, makes it possible to haul several loads per day. On the other hand, short hauls are often made with small trucks and partial loads. (local hauling; i.e., 80 kilometers (1 to 50 miles), is costed at \$3.30per metric ton (\$3per ton). Location factors given in the following section for long distance hauling can be used for geographic adjustments.

7.2.1.2 Long Distance Hauling

Motor transportation rates obtained from Interstate Commerce Commission information (30) are given in Figure 25 as a function of geographic location and distance hauled. Table 61 summarizes the mathematical equations and adjustment factors needed to calculate motor transportation costs directly. Rail shipping costs as a function of distance and geographic location are also shown in Figure 25.

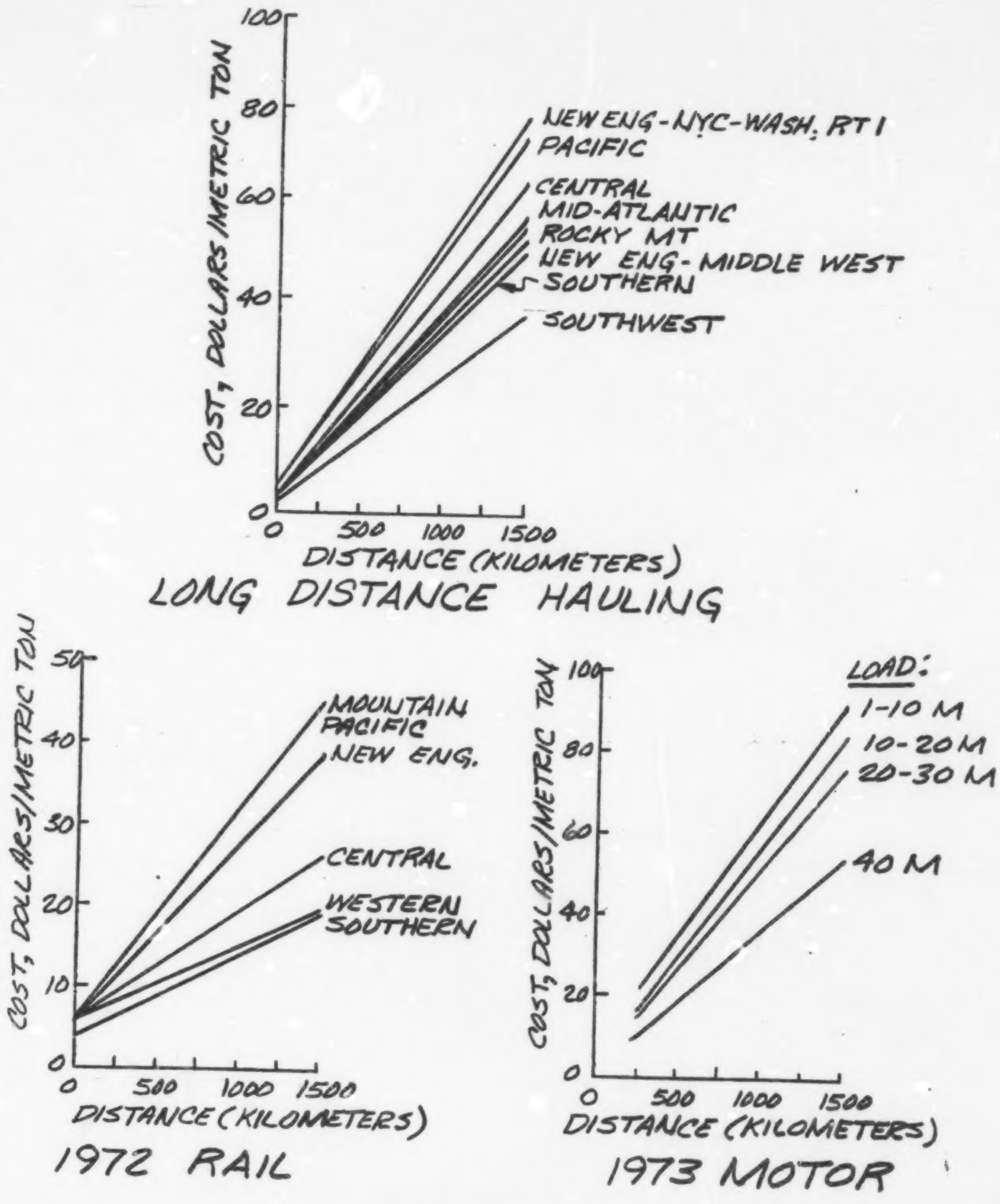

Figure 25. Regional Transportation Costs

Table 61. 1973 U.S. Motor Rate Transportation Rates Estimated From 1971 I.C.C. Information[30]

Terms of Equation

y = 0.91 kkg ($/ton)
x = kilometers (miles)

Equation

$$y = 6.0 + (0.0545x)\ (\text{Region Factor})\ (\text{Density Factor})\ (\text{Load Factor})$$

Density Factor = 0.9

Load Factor:

(1) 18,100 kg (40,000 lbs) = 1.00
(2) 9,100 kg - 13,600 kg (20M - 30 M lbs) = 1.42
(3) 4,500 kg - 9,100 kg (10M - 20 M lbs) = 1.51
(4) 450 kg - 4,500 kg (1M - 10M) = 1.74

Regional Factor:

(1) New England-New York City-Washington Route - 1.41
(2) Pacific-1.34
(3) Central (Ohio, Indiana, Illinois, Michigan)-1.19
(4) Mid-Atlantic (New York, New Jersey, Pennsylvania, West Virginia, Delaware)-1.07
(5) Rocky Mountain-1.02
(6) New England-1.00
(7) Mid-West (Wisconsin, Minnesota, Iowa, Missouri, North Dakota, South Dakota, Nebraska, Kansas)-0.98
(8) Southern (Virginia, Kentucky, North Carolina, South Carolina, Georgia, Florida, Mississippi, Alabama, Tennessee-0.94
(9) Southwest (Texas, Arkansas, Oklahoma, Louisiana)-0.70

The present scattered locations of hazardous waste treatment and disposal facilities make it necessary to haul perhaps 50% of the battery industry wastes distances of 100 to 500 miles. Costs for hauling distances such as these range from \$11 to \$44 per metric ton (\$10 to \$40 per ton) of waste, a major portion of the overall disposal costs. The percentage of wastes requiring long distance hauling may be expected to increase as regulations become more stringent.

7.2.2 Treatment and Disposal Costs

With the exceptions of a few reclamation and recovery operations, solid battery hazardous wastes are usually land stored, landfilled, or buried without treatment. Liquid and sludge wastes on the other hand can be filtered, concentrated, settled, separated, and solidified before final disposal. A relatively small number of contractors are capable of carrying out these operations in any general fashion on the variety of liquids and sludges encountered. A number of these contractors treat and dispose of special segments of these liquid and sludge hazardous materials.

7.2.2.1 Costs for Direct Land Disposal

The lowest cost land disposal of hazardous battery wastes is simple dumping. Dumping costs may be estimated to range from zero to \$1.10 per metric ton (\$1 per ton). Some municipal or county dumps or landfills take local wastes without charge, some of which is hazardous.

7.2.2.2 Landfill Costs

Bulk Solids

Landfill costs for refuse were collected from California (several locations), New Jersey (several locations), Michigan, Illinois (several locations), New York, South Carolina and Pennsylvania. These costs range from \$0 to 6.60 per kkg (\$0 to 6 per ton). Hazardous wastes are undoubtedly coming in to landfills under this category. When properly identified and disposed of according to local regulations, the average costs for easy to handle bulk materials range from \$1.10 to \$6.60 per metric ton \$1 to \$6 per ton) with an average value of approximately \$2.20 per metric ton (\$2 per ton).

Liquids

Disposal of liquids and sludges in landfills is permitted in some states and not in others. Where these are permitted, the disposal costs are usually higher than for bulk solids as shown in Table 62.

Table 62. Bulk Liquid and Sludge Disposal Costs in Landfill Areas

State	Cost*	
	¢/liter (¢/gallon)	$/metric ton ($/ton)
California, Los Angeles	0.4 (1.5)	3.30 (3)
California, Ventura	0.8 (3)	6.60 (6)
Illinois (several sites)	0.8 (3)	6.60 (6)
New Jersey	0.7-0.9 (2.5-3.5)	5.50-7.70 (5-7)
Oklahoma	0.5 (2.0)	4.40 (4)

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*Based on 1.2 kg/liter (10 lbs/gallon).

Table 63. Drum Disposal Costs — Landfill Area

State	Waste	Cost	
		$/208 liter (55 gallon) drum	$/metric ton ($/ton)
Illinois	General	3	16.50 (15)
Illinois	Heavy metals	3-5	16.50-27.50 (15-25)
Illinois	Arsenic	5	27.50 (25)
Oklahoma	General	5	27.50 (25)

Drums

Drums of liquids, sludges, and solids, including hazardous materials, are accepted in many landfills. Table 63 shows some of the charges.

Segregated Burial or Secured Landfill Costs

For very hazardous materials there are a number of secured landfill or burial sites, some of which were initially established for handling radioactive wastes, which provide environmental protection above general landfill operations. These sites cost considerably more than the landfills as shown by Table 64 and are used only where other disposal methods are not adequate.

7.2.3 Contractor Cost Basis Summary

The costs for contractor disposal of general bulk wastes have been discussed previously. The disposal costs for battery industry wastes do not differ substantially from other bulk wastes. Therefore, the following basis was used to determine the costs for private contractor disposal of battery industry wastes:

Disposal Method	Cost
Land storage	\$0-1.1 per kkg (\$0-1 per ton)
Simple landfill	\$4.4 per kkg (\$4 per ton)
Approved landfill	\$6.6 per kkg (\$6 per ton)
Drum disposal	\$16.5 per kkg (\$15 per ton)
Secured landfill	\$30-44 per kkg (\$27-40 per ton)

Reclamation of waste is considered part of the process, therefore, these waste disposal costs are taken as zero.

7.3 Cost References and Rationale

7.3.1 Interest Costs and Equity Financing Charges

Capital investments involve the expenditure of money which must be financed either on borrowed money or from internal equity. Estimates for this study have been based on 10% cost of capital, representing a composite number for interest paid or return on investment required. This value has been established as reasonable by discussions with industry and are compatible with a recent EPA publication.[31]

Table 64. Segregated Burial or Secured Landfill Costs

Location Bulk Materials	Approx. Cost $/0.02m^3 ($/ft^3)	$/kkg ($/ton*)
Illinois	1.30-1.50	38.50-44.00 (35-40)
Texas	1.30-1.50	38.50-44.00 (35-40)
New York	1.50	44 (40)
Idaho	1.00	30 (27)

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*Based on 1.2 kkg/m^3 (1 ton/yd^3)

Drums (Solid or Liquid) - Large

Number of Drums		$/Drum $/kkg ($/ton)
Illinois	10-20	55-110 (50-100)
Nevada	10-20	55-110 (50-100)
Texas	10-20	55-100 (50-100)
New York	10	55 (50)

---

*Based on 182 kg/drum (400 lbs/drum)

NOTE: Single drums may cost as much as $50.

7.3.2 Time Index for Costs

All cost estimates are based on mid-1973 prices and when necessary have been adjusted to this basis using the chemical engineering plant cost index. The inflationary nature of the past year makes it particularly important that this 1973 constant dollar basis be cited for any cost estimation purposes. Appendix C presents published indices which may be used to convert mid-1973 costs to December 1973. In general, costs presented herein are low by approximately 4% in terms of December 1973 dollars.

7.3.3 Useful Service Life

The useful service life of treatment and disposal equipment varies depending on the nature of the equipment and process involved, its usage pattern, maintenance care and numerous other factors. Individual companies have their own service life values based on actual experience and use these values for internal amortization. A second source of such information which, however, is based on other factors less relevant than company experience, is the Internal Revenue Service guidelines.[32]

Based on discussions with industry and condensed IRS guideline information, the following useful service life values have been used:

Facility	Estimated Useful Service Life, Yr.
(1) General Process Equipment	10
(2) Incineration, Distilling and Retorting Equipment	5
(3) Ponds, Lined and Unlined	20
(4) Trucks, Bulldozers, Loaders, and other such materials handling and transporting equipment	5

7.3.4 Depreciation

As the useful life of the treatment and disposal equipment and facilities progresses, their economic value decreases, or depreciates. At the end of their useful life, it is usually assumed that the salvage or recovery value becomes zero. IRS tax allowances, or depreciation charges, provide capital cost recovery based on either service life or accelerated write-off schedules. In effect, the straight line depreciation approach used herein is similar to a conservative depreciation approach which some companies might actually use for income tax purposes. Using a different depreciation rate would have the impact of changing the cash flow companies would actually experience based on reported expenses.

7.3.5 Capital Costs

Capital costs are defined for the purposes of this report as all front-end loaded, out-of-pocket expenditures for the provision of treatment and disposal facilities. These costs include any money for research and development necessary to establish the process, land costs when applicable, equipment, construction and installation, buildings, services, engineering, special start-up costs,and contractor profits and contingencies.

When capital costs are known for a specific plant using a given treatment and disposal technology, cost adjustment to the typical plant size was made using experimental factors. Exponent values of 0.6 for process equipment, 0.8 for situations involving scale-up by use of multiple units or partial process equipment and partial non-volume oriented operations, and 1.0 for treatment and disposal operations that are independent of volume were applied.

7.3.6 Annualized Capital Costs

Almost all capital costs for treatment and disposal facilities are front-end loaded; i.e., most if not all of the money is spent during the first year or two of the useful life. This present worth sum can be converted to equipment uniform annual disbursements by utilizing the Capital Recovery Factor Method:

$$\text{Uniform Annual Disbursement} = \frac{P\ i(1+i)\text{nth power}}{(1+i)\text{nth power} - 1}$$

Where P = present value (capital expenditure) i = interest rate, %/100
n = useful life in years

The capital recovery factor equation above may be rewritten as:

Uniform Annual Disbursement = P(CR - i% - n)

Where (CR - i% - n) is the Capital Recovery Factor for i% interest taken over "n" years useful life.

The capital recovery factor method is used for all annualized capital costs on this report, which, in effect, would be similar to constant annual payments on principal and interest were the capital facilities paid for through a constant payment mortgage.

7.3.7 Treatment of Land Costs

Land-destined hazardous wastes require removal of land from other economic use. The amount of land tied up will depend on the treatment and disposal method employed and the amount of wastes involved. Although land is non-depreciable according to IRS regulations, there are numerous instances where the market value of the land for land-destined wastes has been significantly reduced permanently, or actually becomes unsuitable for future use due to the nature of the stored waste. Therefore, costs estimates have assumed land values and capital recovery on the following basis:

(a) If land requirements for on-site treatment and disposal are not significant, then no cost allowance has been made.

(b) Where on-site land requirements are significant and the storage or disposal of wastes does not affect the ultimate market value of the land, cost estimates include only interest on invested money.

(c) For significant on-site land requirements where the ultimate market value or availability of the land has been seriously reduced, cost estimates include both capital depreciation and interest on invested money.

(d) Off-site treatment and disposal land requirements and costs are not considered directly. It is assumed that land costs are included in the overall contractor's fees along with its other expenses and profit.

In view of the extreme variability in land costs, no attempt has been made to set different land values for each plant, industry,or location. Instead, a constant value of $12,350 per hectare ($5000 per acre) has been used throughout. Where land costs are a major portion of on-site storage and disposal costs discussions and figures have been used to demonstrate the sensitivity of costs to land value.

7.3.8 Operating Expenses

Annual costs of operating the treatment and disposal facilities include labor, supervision, materials, maintenance, taxes, insurance,and power and energy. Operating costs combined with annualized capital costs give the total costs for treatment and disposal operations. No interest cost was included for operating (working) capital. Since working capital might be assumed to be one sixth to one third of annual operating costs (excluding depreciation), about 1 to 2% of total operating costs might be involved. This is considered to be well within the accuracy of the estimates.

(a) Labor and Supervision Costs

Based on discussions with industry plant management personnel, the following costs were used for labor and supervisory needs.

Category	$/hour (mid-1973)
Process operators, Plant laborers	7.50
Truck driver, Equipment operators	8.50
Supervision	10.00

The above figures include wages, fringe benefits, and plant overhead.

(b) Taxes and Insurance

Taxes and insurance are taken as 2% of invested capital, excluding research and development.

(c) Other Operating Costs

Operating costs for maintenance, materials,and power and energy are variable for each individual case.

7.4 Definition of Technology Levels

Costs are developed for three levels of technology consistent with those defined in Phase III. These definitions redefined, with pertinent comments, are:

Level I

Technology currently employed by typical facilities; i.e., broad average present treatment and disposal practice. For most large volumed wastes two or three options are required to cover the different technologies utilized.

Level II

Best technology currently employed. Identified technology at this level must represent the soundest process from an environmental and health standpoint, currently in use in at least one location. Installations must be commerical scale; pilot plant and bench scale installations are not suitable. For battery land-destined hazardous wastes this level may in a number of instances be similar to Level I.

Level III

Technology necessary to provide adequate health and environmental protection. Level III may be more or less sophisticated or may be identical with Level I or II technology. At this level, identified technology may include pilot or bench scale processes providing the exact stage of development is identified. One pertinent difference between Level III technology and Levels I and II technology is that it is not necessary that at least one location be using this technology. Technology transfers from other industries may be included.

7.5 Individual Battery Hazardous Waste Disposal and Treatment Costs

7.5.1 SIC 3691, Storage Batteries Waste Disposal

Costs for treatment and disposal of hazardous wastes from the storage battery industry are summarized in the following text and Tables 65 through 68.

7.5.1.1 Lead Acid Battery

The character of the waste sludge from a lead acid battery plant is determined largely by the type of water treatment used. Relatively large volume sludges are produced from lime treatment, containing approximately 0.01% lead. Caustic treatment produces a concentrated sludge of much smaller volume containing approximately 58% lead. In this industry, many plants do not remove lead from their wastewater at the present time due to either meeting effluent regulations existing in their locality or due to lack of regulation. It is anticipated that in the future more plants will be required to treat their wastewater.

Several plants reclaim the lead from the small volume caustic treatment. Coagulating agents, if used, decrease the possibility of reclaim. If the sludge from caustic treatment is not reclaimed, it should be deposited in a secured landfill, due to the high lead content. Because of the much smaller concentration of lead in the calcium sulfate sludge obtained from lime water treatment, an approved landfill should prove environmentally safe. Monitoring of the leachate and runoff should give adequate notice for further safeguards, if needed.

Chemical fixation of the calcium sulfate sludge is an interesting alternative in the pilot stage of development for battery sludges. Several commercial processes are available whereby sludge is converted to a "non-leachable" solid material. One process forms a concrete like material suitable for construction purposes. The leaching characteristics of the product warrant long term study to definitely prove this process.

Typical plant costs for treatment and disposal of calcium sulfate sludge presented in Table 65 are determined for on-site disposal. Those for caustic sludge disposal in secured landfills presented in Table 66 are based on outside contractor costs. A detailed example of the cost estimate for disposal of calcium sulfate sludge on-site is presented in Appendix D as illustrative of the following cost tables.

7.5.1.2 Nickel-Cadmium Storage Cell

There are two land destined hazardous waste streams from nickel-cadmium battery production. These are scrap cells, and sludge from wastewater treatment. These two waste streams are often treated to reclaim the hazardous components. When this is done, it is considered a part of the process and zero hazardous waste disposal cost is assumed.

The wastewater is treated with caustic soda as a precipitating agent and pumped to a settling tank or pond for disposal of the sludge. A study concerning the migration of hazardous materials through soil has given preliminary indications that the migration of cadmium hydroxide and nickel hydroxide is minimal in neutral and alkaline soil, due to their extremely low solubilities. Under acidic conditions, however, the metal hydroxides become much more soluble. Chemical fixation of the sludge may be used before ponding to insure against migration of materials. Chemical fixation has shown success on sludges from other industries in preventing leaching. Its suitability to this sludge must be determined. Projected costs are taken at approximately \$500 due to the small volume of sludge involved.

If the sludge is not treated or reclaimed, secured landfill is recommended, due to the high concentrations of hazardous materials. The composition of the sludge is 35% nickel hydroxide and 65% cadmium hydroxide on a dry basis. The sludge is assumed to be 35% solids. The scrap waste stream consists of 12% nickel, 43% cadmium and 45% non-hazardous materials.

The costs for treatment and disposal of hazardous wastes from a typical nickel cadmium battery plant are presented in Tables 67 and 68. The relatively small volume of wastes involved make it difficult to estimate the detailed cost meaningfully. The secured landfilling of sludge and scrap is determined by outside contractor costs, due to the relatively small volume of waste from the typical plant.

Table 65. Lead Acid Battery Typical Plant Costs For Treatment and Disposal

	Production Rate	Location	Process
Typical Plant:	8,200 kkg/yr	Eastern U.S.	Dry and Wet Charge

Identification of Waste Stream:	Composition	Form	Amount to Treatment/Disposal
Lime Wastewater Treatment Sludge	Calcium Sulfate Water 150 ppm Lead	Sludge (35% Solids)	2,100 kg/kkg product or 17,290 kkg/year

	Dollars (1973)			
T/D Level	Level I	Level II	Level III	
Technology	1	1	1	2
Investment Costs:				
Land	1,770	1,770	1,770	1,770
Other	19,750	100,000	19,750	29,750
Total Investment	21,520	101,770	21,520	31,520
Annual Costs:				
Cost of Capital	5,210	21,480	5,210	7,200
Operating Costs	18,460	18,860	18,460	28,460
Energy & Power	1,000	1,000	1,000	1,000
Contractor			66,778	
Total Annual Costs	26,840	43,110	91,448	36,660
Cost/kkg of product	3.27	5.26	11.15	4.47
Cost/kkg of waste	1.55	2.49	5.29	2.12

Treatment/Disposal Technology

Level I	— Simple land storage (On-site)
Level II	— Land storage with leachate collection and treatment (On-site)
Level III(1)	— Chemical fixation and landfill (Cost assumed to be $3.86/kkg for fixation.)
Level III(2)	— Approved landfill.

Table 66. Lead Acid Battery Typical Plant Costs For Treatment and Disposal

	Production Rate	Location	Process
Typical Plant:	8,200 kkg/yr	Eastern U.S.	Dry and Wet Charge

Identification of Waste Stream:	Composition	Form	Amount to Treatment/Disposal
Caustic Soda Wastewater Treatment Sludge	Lead Hydroxide Lead Sulfate, and Water	Sludge (80% Solids)	0.5 kg/kkg product or 4.46 kkg/yr

	Dollars (1973)					
T/D Level	Level I		Level II		Level III	
Technology	1	2	1	2	1	2
Investment Costs:						
Land						
Other	1,000					
Total Investment	1,000	0	0	0	0	0
Annual Costs:						
Cost of Capital	200					
Operating Costs	1,000					
Energy & Power	200					
Contractor		<500	<500		1,000	
Total Annual Costs	1,400	<500	<500	0	1,000	0
Cost/kkg of product	0.17	<0.10	<0.10	0	0.12	0
Cost/kkg of waste	314	<112	< 112	0	224	0

Treatment/Disposal Technology

Level I(1) — Simple landfill (On-site)
Level I(2) — Simple landfill (Off-site contractor)
Level II(1) — Simple landfill (Off-site)
Level II(2) — Reclaim of lead
Level III(1) — Secured landfill (Based on outside contractor costs)
Level III(2) — Reclaim of lead

Table 67. Nickel Cadmium Battery Typical Plant Costs For Treatment and Disposal

	Production Rate	Location	Process
Typical Plant:	447 kkg/yr	Eastern U.S.	Sintered Plate Impregnation

Identification of Waste Stream:	Composition	Form	Amount to Treatment/Disposal
Scrap Cells	Nickel, Cadmium, and 45% non-hazardous materials	Solid scrap and cells	12 kg/kkg product or 5.4 kkg/yr

	Dollars (1973)			
T/D Level	Level I	Level II	Level III	
Technology	1	1	1	2
Investment Costs:				
Land				
Other				
Total Investment	0	0	0	0
Annual Costs:				
Cost of Capital				
Operating Costs				
Energy & Power				
Contractor	100		500	
Total Annual Costs	100	0	500	0
Cost/kkg of product	0.22	0	1.12	0
Cost/kkg of waste	18.52	0	92.60	0

Treatment/Disposal Technology

Level I — Simple landfill (On-site)
Level II — Sale to outside scrap reclaimer
Level III(1) — Secured landfill (Contractor)
Level III(2) — Sale to outside scrap reclaimer

Table 68. Nickel Cadmium Battery Typical Plant Costs For Treatment and Disposal

	Production Rate	Location	Process
Typical Plant:	447 kkg/yr	Eastern U.S.	Sintered Plate Impregnation

Identification of Waste Stream:	Composition	Form	Amount to Treatment/Disposal
Water Treatment Sludge	Nickel Hydroxide, Cadmium Hydroxide, Water	Sludge (35% Solids)	20 kg/kkg or 8.9 kkg/yr

	Dollars (1973)				
T/D Level	Level I	Level II	Level III		
Technology	1	1	1	2	3
Investment Costs:					
Land					
Other	1,000		1,000		
Total Investment	1,000	0	1,000	0	0
Annual Costs					
Cost of Capital	200		200		
Operating Costs	1,500		1,500		
Energy & Power	250		250		
Contractor			500	1,000	
Total Annual Costs	1,950	0	2,450	1,000	0
Cost/kkg of product	4.36	0	5.48	2.24	0
Cost/kkg of waste	220	0	275	112	0

Treatment/Disposal Technology

Level I — Simple land storage (On-site)
Level II — Sale to outside scrap reclaimer
Level III(1) — Chemical fixation and simple landfill (Contractor)
Level III(2) — Secured landfill (Contractor)
Level III(3) — Sale to outside scrap reclaimer

7.5.1.3 Cadmium-Silver Oxide and Zinc-Silver Oxide Batteries

The hazardous waste streams from the production of these cells are similar to those of the nickel cadmium cell being generated from scrap cells containing cadmium, zinc, and silver, and water treatment sludges.

In the typical cadmium-silver oxide plant and zinc-silver oxide plant all hazardous wastes are reclaimed, and thus there is no hazardous waste to land. The reclaiming is considered a process operation and treatment and disposal costs are taken as zero.

7.5.2 Treatment and Disposal of SIC 3692 Primary Batteries Hazardous Wastes

The potentially hazardous wastes destined for land disposal from the manufacture of primary batteries, primarily consists of reject or scrap cells. However, in the production of magnesium-carbon and lead-reserve cells, wastewater treatment sludges are produced. At the present time, scrap cell wastes are disposed of in land dumps or simple landfills. The water treatment sludges are either sold or land disposed.

In the case of scrap cell wastes, the volume is relatively small, while the concentration of potentially hazardous materials is high. Because of these two factors, the most environmentally adequate disposal is in a secured landfill as discussed in Section 6.0. This procedure would not only insure against possible migration of hazardous materials, but would provide a permanent record of their disposal.

The hazardous wastes generated by the primary batteries industry are, in general, small in volume, making it uneconomical for the plants to absorb the capital cost of the landfill operation themselves. Thus, most plants either hire contractors or utilize municipal facilities for waste disposal. Accordingly, the costs herein presented reflect contractor disposal costs, as opposed to on-site or plant disposal costs. The rates are assumed (not including transportation) using contract disposal for the corresponding technique.

simple landfill	$10 per kkg
approved landfill	$35 per kkg
secured landfill	$50 per kkg

The total annual cost to convert a suitable local landfill to a secured landfill is approximately $14,000.

In determining transportation costs to the nearest secured landfill, a cost of $100 per kkg was assumed for 1 to 5 kkg loads over 402.5 kilometers (250 miles). For larger loads, I.C.C. line-haul costs were used as presented in an earlier section (approximately $50 per kkg for 10 kkg loads).

The following Tables 69 through 75 and text summarize the annual treatment and disposal costs for typical plants.

7.5.2.1 Carbon-Zinc

This cell is produced in the largest quantity of any primary cell manufactured in the U.S. The hazardous wastes to land are scrap and reject cells. The amount of waste is estimated to be about 1% of production for a typical plant. It is estimated that the waste stream contains approximately 19% zinc, 2.5% zinc chloride, 1% mercury, and smaller amounts of lead and cadmium.

The successful implementation of a disassembly and recovery process would reduce significantly the hazardous materials presently going to landfill from this category. The mercury, lead, cadmium, and about 60% of the zinc could be reclaimed, if disassembly of the cell could be economically achieved. In one pilot study the use of paper separators is aiding in disassembly, and is showing promising results. The cost for the typical plant is based upon the use of contractor disposal.

7.5.2.2 Alkaline Cell

This cell is produced in the second largest quantity of any primary cell manufactured in the United States. Hazardous wastes to land consist entirely of scrap and reject cells. The waste is estimated to be about 1% of production for a typical plant. The waste contains about 1% mercury and 16% zinc. The costs for the typical plant are based on the use of contractor disposal.

7.5.2.3 Air Cell

This is a specialty battery. Its hazardous wastes to land consist entirely of scrap and reject cells, containing 0.1% mercury and 30% zinc. A 1% waste to production ratio is assumed for a typical plant. The costs for the typical plant was based upon the use of contractor disposal.

7.5.2.4 Mercury Ruben Cell

Hazardous waste from the production from this cell consists exclusively of scrap cells. In the great majority of cases this waste is reclaimed by smelting. Reclaiming is done either by the plant themselves or a private contractor. The final waste going to landfill is slag from the reclaim furnace. This is estimated to be 1% mercury and 56% zinc. The costs for the typical plant are based on the use of contractor disposal.

Table 69. Carbon Zinc Battery Typical Plant Costs For Treatment and Disposal

	Production Rate	Location	Process
Typical Plant:	2,270 kkg/yr	Eastern U.S.	Standard

Identification of Waste Stream:	Composition	Form	Amount to Treatment/Disposal
Reject and scrap cells	Zinc, Zinc Chloride Mercury, Cadmium, Lead and 78% non-hazardous materials	Solid	1 kg/kkg product or 22.7 kkg/yr

	Dollars (1973)			
T/D Level	Level I	Level II	Level III	
Technology	1	1	1	2
Investment Costs:				
Land				
Other				
Total Investment	0	0	0	0
Annual Costs:				
Cost of Capital				
Operating Costs				
Energy & Power				
Contractor	2,500	3,020	3,635	
Total Annual Costs	2,500	3,020	3,635	0
Cost/kkg of product	1.10	1.33	1.60	0
Cost/kkg of waste	110	133	160	0

Treatment/Disposal Technology

Level I — Simple landfill (Off-site Contractor)
Level II — Landfill with leachate surveillance (Contractor)
Level III(1) — Secured landfill (Contractor)
Level III(2) — Disassembly and reclaim (In-plant)

Table 70. Alkaline Manganese Battery Typical Plant Costs For Treatment and Disposal

	Production Rate	Location	Process
Typical Plant:	2,000 kkg/yr	Eastern U.S.	Standard

Identification of Waste Stream:	Composition	Form	Amount to Treatment/Disposal
Reject and scrap cells	Mercury, Zinc and 83.7% non-hazardous	Solid	1 kg/kkg product or 20 kkg/yr

	Dollars (1973)			
T/D Level	Level I	Level II	Level III	
Technology	1	1	1	2
Investment Costs:				
Land				
Other				
Total Investment	0	0	0	0
Annual Costs				
Cost of Capital				
Operating Costs				
Energy & Power				
Contractor	2,200	2,660	3,000	0
Total Annual Costs	2,200	2,660	3,000	0
Cost/kkg of product	1.10	1.33	1.50	0
Cost/kkg of waste	110	133	150	0

Treatment/Disposal Technology

Level I — Simple landfill (Off-site contractor)
Level II — Landfill with leachate surveillance (Contractor)
Level III(1) — Secured landfill (Contractor)
Level III(2) — Disassembly and reclaim (In-plant)

Table 71. Air Cell Battery Typical Plant Costs For Treatment and Disposal

	Production Rate	Location	Process
Typical Plant:	1,540 kkg/yr	Eastern U.S.	Standard

Identification of Waste Stream:	Composition	Form	Amount to Treatment/Disposal
Reject and scrap cells	Mercury, Zinc and 70% non-hazardous materials	Solid	1 kg/kkg product or 15.4 kkg/yr

	Dollars (1973)			
T/D Level	Level I	Level II	Level III	
Technology	1	1	1	2
Investment Costs:				
Land				
Other				
Total Investment	0	0	0	0
Annual Costs:				
Cost of Capital				
Operating Costs				
Energy & Power				
Contractor	1,695	2,048	2,310	
Total Annual Costs	1,695	2,048	2,310	0
Cost/kkg of product	0.85	1.02	1.16	0
Cost/kkg of waste	85	102	116	0

Treatment/Disposal Technology

Level I — Simple landfill (Off-site contractor)
Level II — Same as Level I
Level III(1) — Secured Landfill (Contractor)
Level III(2) — Disassembly and reclaim

Table 72. Mercury Ruben Battery Typical Plant Costs For Treatment and Disposal

	Production Rate	Location	Process
Typical Plant:	453 kkg/yr	Eastern U.S.	Ruben Cell

Identification of Waste Stream:	Composition	Form	Amount to Treatment/Disposal
Slag from reclaim furance	Mercury, Zinc and 43% non-hazardous materials	Solid	8 kg/kkg product or 3.6 kkg/yr

	Dollars (1973)		
T/D Level	Level I	Level II	Level III
Technology	1	1	1
Investment Costs:			
Land			
Other			
Total Investment	0	0	0
Annual Costs:			
Cost of Capital			
Operating Costs			
Energy & Power			
Contractor	<500	<500	1000
Total Annual Costs	<500	< 500	1000
Cost/kkg of product	1.10	1.10	2.20
Cost/kkg of waste	139	139	278

Treatment/Disposal Technology

Level I — Simple landfill (Contractor)
Level II — Simple landfill (Contractor)
Level III — Secured landfill (Contractor)

7.5.2.5 Mercury Weston Cell

This is a limited production cell. Its wastes are assembled rejected batteries. Hazardous materials in the waste are estimated to be 18.5% mercury, 6.2% mercury sulfate, 7.9% cadmium sulfate, and 4.4% cadmium. Present disposal practice is indefinite on-site storage. The assembled cells are completely encased which reduces their hazardousness while in storage. However, the potential release of these materials, particularly soluble mercury and cadmium, definitely places them in the hazardous waste category. Secured landfill is indicated for Level III disposal. The costs for the typical plant are based on the use of contractor disposal.

7.5.2.6 Magnesium Carbon

This battery is produced primarily for military use. It is unique in that no hazardous materials are contained in its reject cells. However, trivalent chromium sludge is produced from water treatment. This sludge in the case of one plant, was sold to a refractory brick manufacturer. Either chemical fixation or secured landfill are recommended for Level III technology for land disposal. The costs for the typical plant are based on the use of contractor disposal.

7.5.2.7 Lead Acid Reserve

The lead-fluoboric acid reserve cell wastes are scrap cells and scrap metals. Hazardous materials in the scrap are estimated to be 55% lead and 31% nickel. Future water quality standards will probably result in a sludge from water treatment. The sludge is estimated to be 26% lead hydroxide and 74% nickel hydroxide (dry basis). At present, one plant is in the planning stages of a water treatment process, but no plant as yet is utilizing one.

The largest volume of waste is scrap metals from battery production (30% of product). Much of the cost of the recommended secured landfill could be eliminated if these materials were recyclable. The costs for the typical plant are based on the use of contractor disposal.

Table 73. Mercury Weston Battery Typical Plant Cost For Treatment and Disposal

	Production Rate	Location	Process
Typical Plant:	0.9 kkg/yr	Eastern U.S.	Weston Cell

Identification of Waste Stream:	Composition	Form	Amount to Treatment/Disposal
Reject and scrap cells	Mercury, Cadmium Mercurous Sulfate, Cadmium Sulfate and 67% non-hazardous materials	Scrap Cells	10 kg/kkg product or 0.009 kg/yr

	Dollars (1973)		
T/D Level	Level I	Level II	Level III
Technology	T	T	T
Investment Costs:			
Land			
Other			
Total Investment	0	0	0
Annual Costs:			
Cost of Capital			
Operating Costs			
Energy & Power			
Contractor			< 500
Total Annual Costs	0	0	<500
Cost/kkg of product	0	0	*
Cost/kkg of waste	0	0	*

Treatment/Disposal Technology

Level I	— In-plant storage (Considered to be part of production cost)
Level II	— Same as Level I
Level III	— Secured landfill

*Waste amounts from this plant are so small that disposal costs per ton of product or waste are meaningless.

Table 74. Magnesium Carbon Battery Typical Plant Costs For Treatment and Disposal

	Production Rate	Location	Process
Typical Plant:	1,350 kkg/yr	Eastern U.S.	Standard

Identification of Waste Stream:	Composition	Form	Amount to Treatment/Disposal
Waste Water Treatment Sludge	Chromium Hydroxy-Carbonate	Sludge (50% Solids)	27.6 kg/kkg product or 37.5 kkg/yr

	Dollars (1973)				
T/D Level	Level I	Level II		Level III	
Technology	1	1	2	1	2
Investment Costs:					
Land					
Other	1,000	1,000		1,000	
Total Investment	1,000	1,000	0	1,000	
Annual Costs:					
Cost of Capital	200	200		200	
Operating Costs	1,000	1,000		1,000	
Energy & Power	200	200		200	
Contractor				500	4,000
Total Annual Costs	1,400	1,400	0	1,900	4,000
Cost/kkg of product	1.04	1.04	0	1.41	2.96
Cost/kkg of waste	37.34	37.34	0	50.67	107

Treatment/Disposal Technology

Level I — Simple landfill (On-site)
Level II(1) — Simple landfill
Level II(2) — Sale for non-clay refractory manufacture
Level III(1) — Chemical fixation and simple landfill (On-site)
Level III(2) — Secured landfill

Table 75. Lead Acid Reserve Battery Typical Plant Costs For Treatment and Disposal

	Production Rate	Location	Process
Typical Plant:	45 kkg/yr	Eastern U.S.	Plated Strip

Identification of Waste Stream:	Composition	Form	Amount to Treatment/Disposal
Scrap and Reject Cells	Lead and Nickel	Solid	330 kg/kkg product or 15 kkg/yr
Wastewater Treatment Sludge	Lead and Nickel Hydroxides	Sludge (35% Solids)	8.2 kg/kkg product or 0.37 kkg/yr

	Dollars (1973)		
T/D Level	Level I	Level II	Level III
Technology	1	1	1
Investment Costs:			
Land			
Other			
Total Investment	0	0	0
Annual Costs:			
Cost of Capital			
Operating Costs			
Energy & Power			
Contractor	2,000	2,000	3,500
Total Annual Costs	2,000	2,000	3,500
Cost/kkg of product	44.45	44.45	77.78
Cost/kkg of waste	130	130	228

Treatment/Disposal Technology

Level I — Simple landfill of scrap and reject cells (Contractor). No water treatment and no sludge generated.
Level II — Same as Level I
Level III — Secured landfilled of scrap and sludge (Contractor)

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APPENDIX A

PHYSICAL, CHEMICAL, BIOLOGICAL AND ENVIRONMENTAL PROPERTIES OF HAZARDOUS MATERIALS

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Cadmium and Its Compounds

A. Physical/Chemical Properties

Elemental Cadmium (Cd)

Cadmium (at. wt. 112.4 grams, m.p. 321° C, b.p. 767° C, d. 8.6)[9] occurs as a silver-white blue-tinged lustrous metal which oxidizes in moist air.[1] It is insoluble in water, slowly soluble in hot HCl, almost unattacked by cold H_2SO_4, but converted into sulfate by hot H_2SO_4.[1] Cadmium is readily soluble in dilute HNO_3 and in ammonium nitrate solutions. One hundred grams Hg dissolves 5.17 grams of cadmium at 18° C.[1] Solutions of cadmium yield with H_2S or Na_2S a yellow precipitate which is insoluble in excess Na_2S.[1]

In the elemental form cadmium is insoluble in water.[3] Although the chloride, nitrate, and sulfate of cadmium are highly soluble in water, the carbonate and hydroxide are virtually insoluble. Hence at high pH values, cadmium will be precipitated out.[5]

Cadmium Oxide (CdO)

CdO (m.wt. 128.41 g, d. 8.15)[9] exists in two species; as either a dark brown infusible amorphous powder or as cubic. brown crystals.[4] Both decompose on heating at 900° C and sublime at 1559° C.[9,3] Cadmium oxide is soluble in dilute acids and ammonium salts.[1] Because of its amphoteric nature, its solubility increases as its pH decreases. At pH 11.3, cadmium oxide's solubility in water is 0.094 ppm as Cd^{++} while at pH 9 its saturation point is 761.0 ppm as Cd^{++}.[20]

Cadmium Hydroxide ($Cd(OH)_2$)

Cadmium hydroxide (m.w. 146.43[1], m.p. 300° C, d. 4.79) is a white powder[4] consisting of trigonal or amorphous crystals.[3] It is soluble in ammonium hydroxide and dilute acid and virtually insoluble in water (2.6 mg/liter at 25° C)[9] and alkalis.[4] Cadmium hydroxide absorbs carbon dioxide from the air[4]; dehydration to CdO occurs at 130° C-200° C.

Cadmium Sulfate ($CdSO_4 \cdot 0\text{-}7H_2O$)

Cadmium sulfate occurs in several hydrated forms in addition to an anhydrous form. Anhydrous cadmium sulfate (formula $CdSO_4$, m.w. 208.48, d. 4.69, m.p. 1000° C)[3] is a white powder of colorless, odorless rhomboidal crystals[3] [9] which is very soluble in water (755.0 g/liter at 0° C, 608.0 g/liter at 100° C) and insoluble in alcohol.[4] The properties of the hydrated forms are given below; all are very soluble in water and almost insoluble in alcohol.[4, 3]

$CdSO_4 \cdot H_2O$: m.w. 226.48, d. 3.79, transition pt. 108° C, monoclinic crystals[9]
$CdSO_4 \cdot 4H_2O$: m.w. 280.48, d. 305[4]
$CdSO_4 \cdot 7H_2O$: m.w. 334.57, d. 2.48, transition pt. 40° C, colorless monoclinic crystals[9]
$3CdSO_4 \cdot 8H_2O$: m.w. 769.50, d. 3.09, transition pt. 4° C colorless, odorless monoclinic crystals, H_2O solubility at 0° C 1130.0 g/liter[1, 9]

Cadmium Nitrate ($Cd(NO_3)_2$)

Cadmium nitrate exists in two forms hydrated and anhydrous. Anhydrous cadmium nitrate (m.w. 236.41, m.p. 350° C) is a colorless compound which is very soluble in water (1090 g/liter at 0° C, 3260 g/liter at 60° C, 6820 g/liter at 100° C) and alcohol, and is soluble in ethyl acetate.[9] Cadmium nitrate tetrahydrate (formula $Cd(NO_3)_2 \cdot 4H_2O$, n.w. 308.47, d. 2.455, m.p. 59.4° C, b.p. 132° C[9]) is a white substance composed of amorphous or hygoscopic needles.[4] It is very soluble in water (2150 g/liter in cold water), soluble in alcohol and ammonia and virtually insoluble in nitric acid.[4]

B. Biological Properties

Cadmium is absorbed into the human organism without regard to the amount already stored, nor does there appear to be a mechanism to maintain a constant level in blood and body fluids.[8] Of 50-60 micrograms taken into the system daily, about 2 micrograms are retained mainly in the kidney and liver, the rest is eliminated in the feces. Cadmium has no known biologic function. It is toxic to practically all systems and functions of the human and animal organism.[8] Cadmium inhibits the functions of enzymes containing the sulfhydrile (SH) groups, which are dependent on the presence of zinc, cobalt, and other metals. There is evidence that cadmium acts upon the smooth muscle of the blood vessels, either directly or indirectly through the agency of the kidneys.

The concentration and not the absolute amount determines the acute toxicity of cadmium.[15] Acute poisoning may result from the inhalation of cadmium dusts and fumes (usually CdO) and from the ingestion of cadmium salts. Inhaled as a dust or aerosol, cadmium salts (including even the relatively insoluble oxide) probably have a toxicity rating of "supertoxic" (with a LD equal to or less than 5 mg/kg body weight) in man, with death from fatal pulmonary injury. When swallowed, cadmium compounds are much less lethal than when inhaled, in part because they induce vomiting and so are not retained. Although as little as 30 mg of soluble cadmium salts has produced severe toxic symptoms when ingested, death probably requires several hundred mg by the oral route. A severe gastroenteritis is the chief response to ingested cadmium, but both kidney and liver injuries may occur and the kidney disorder has killed experimental animals. In man the kidney damage appears to be secondary to the appearance of a low molecular weight protein in the urine. Cadmium produces more profound changes in urinary excretion of amino acids than do lead and mercury; urinary concentrations of hydroxyamino acids, threonine and serine are particularly elevated.[2]

Finely divided cadmium of a critical particle size is inflammable and may generate lethal fumes of cadmium oxide.[9] The inhalation of 40 mg of cadmium with the pulmonary retention of 4 mg has been estimated to be fatal in man.[2] In contrast to intoxication by ingestion of cadmium, the deleterious activities following inhalation of cadmium dust or fumes are largely limited to the lungs and respiratory mucosa; although acute renal necrosis can sometimes be precipitated by inhaled cadmium fumes.[2] Even brief exposure to high concentrations may result in pulmonary edema and necrosis of the pulmonary epithelium. Other symptoms precipitated by minor exposure include dryness of the throat, coughing, headache, a sense of constriction in the chest, shortness of breath (dyspnea) and vomiting.

A characteristic sign of chromic cadmium poisoning is a mycrocytic hypochronic anemia; another significant finding from a diagnostic standpoint may be the formation of a yellow ring as a part of the tooth structure in chronically exposed men.[2] A severe disabling emphysema without clinical or histological evidence of chronic bronchitis was the uniform syndrome exhibited by men chronically poisoned with cadmium fumes.[8]

With regard to the toxicity of cadmium toward fish, cadmium can disrupt energy production by the inhibition of oxygen uptake.[6] Within the cells, this disruption can occur at relatively low levels and be of such severity as to cause the deaths of fish, particularly the blue gill.[6] Because cadmium acts synergistically with other substances to increase toxicity, the lethal concentration for fish varies from 0.01-10.0 mg/liter depending on the test animal, type of water, temperature, and length of exposure.[5]

C. Environmental Properties

The water quality standard for cadmium and its compounds is 0.01 ppm.[6]

One of the problems with heavy metals is their tendency to concentrate through both aquatic and terrestrial food chains.* Aquatic macro- and micro-flora and fauna accumulate heavy metals such as cadmium in body tissues in significantly greater concentrations than present in the surrounding environment. These organisms are the food source for fish and insects which retain the cadmium in the tissues of the consumed organisms; this process continues to the organisms at the top of the pyramidal food chain, such as man and large carnivorous birds and mammals. The more links in the chain, the more severe the bioaccumulation phenomenon.

D. Radioactive Properties

None

Chromium and Its Compounds

A. Chemical/Physical Properties

Chromium Hydroxide ($Cr(OH)_3 \cdot nH_2O$)

The solubility of this amphoteric green gelatinous precipitate[4] varies significantly with pH[20]. In the presence of chloride ions, it is least soluble at pH 8.5; 2.61×10^{-11} g Cr^{+3} is present in one liter of saturated solution. At pH 9, 3.28×10^{-11} g Cr^{+3}/liter remain in solution; at pH 7, 3.28×10^{-10} g Cr^{+3}/liter remain in solution. As the pH becomes more acidic the rate of solubilization increases rapidly. At pH 5 a saturated solution of $Cr(OH)_3 \cdot nH_2O$ will contain 5.2×10^{-1} g Cr^{+3}/liter. At pH 3, 5.2×10^{3} g Cr^{+3} will dissolve in a liter of water.[20]

In the absence of chloride ions chromium hydroxide is dramatically less soluble. At pH 5 the saturation concentration is 2.07×10^{-9} g Cr^{+3}/liter; at pH 7 and 9 the saturation concentration is below 5.2×10^{-18} g Cr^{+3}/liter. Please note that the data for $Cr(OH)_3$ in the absence of chloride ions may be too low. There is some indication that this is theoretical data for the non hydrated form which is nonexistent.[20]

Chromium hydroxide can be decomposed to chromic oxide (Cr_2O_3) by heat.[4]

Chromic Oxide (Cr_2O_3)

The light to dark green trigonal crystals of chromic oxide (m.w. 151.99, d. 5.21, m.p. 2435° C, b.p. 4000° C)[9] turn brown on heating but revert to a green color on cooling.[1] Because of this oxide's amphoteric nature its solubility is pH-dependent. Chromic oxide is least soluble at pH 7 (1.51×10^{-10} g Cr^{+3}/liter) in solutions devoid of chloride ions.[20] In the absence of chloride ions, at a pH 9, a saturated solution will contain 0.0126×10^{-3} g Cr^{+3}/liter.[20] Acid treatment solubilizes chromic oxide at a pH of 1, its solubility is above 52 g/liter.

Other Trivalent Chromic Salts

The nitrate and sulfate salts are readily soluble in water, but the carbonate is quite insoluble.[5] Neutralization of the soluble salts precipitates $Cr(OH)_3 \cdot nH_2O$.

Hexavalent Chromium Salts

Of these compounds only the sodium, potassium and ammonium chromates are soluble.[5] Hexavalent chromium can be reduced to the trivalent form by heat, organic matter or reducing agents.

B. Biological Properties

Trivalent Chromium Compounds

Trivalent chromium compounds are said to be less toxic than the hexavalent chromium compounds.[6] Eczema-like skin conditions from trivalent chromium contact have been reported. The toxicology literature discusses the hexavalent compounds in considerable detail but the available literature does not distinctly describe the hazardous properties of the trivalent compounds by themselves.[8] Internally, chrome salts act as an irritant causing tissue corrosion in the gastronintestinal tract. Complaints of bad taste in the mouth, vomiting and bloody stools are often noted. In addition, the central nervous system is often involved and dilated pupils, coma, collapse, slow respiration, shock and death sometimes occur.[8] In contact with the skin, chromium metal and Cr^{+3} combine with proteins to form complexes in the superficial layers.

Hexavalent Chromium Compounds

The water soluble hexavalent compounds are extremely irritating, corrosive, and toxic to human body tissue; they penetrate surface tissue before they react. Insoluble chromium compounds, on the other hand, are retained in the lungs over extended periods of time and play a role in the production of lung cancer.[8] Chromium in the hexavalent form is clearly a cause of ulceration and perforation of the nasal septum.[8] The septum is particularly susceptible to the action of chromium not only because of the immediate contact of inhaled particles with the septum, but also because of its structure; i.e., the mucous membrane covering this area is far less vascular than the mucous membrane lining the rest of the nasal fossae and thus is easily destroyed. Other sites where ulcers may appear as a result of contact with chromium $^{+6}$ are the skin, the roots of the fingernails, the knuckles, the eyelids, the edges of the nostrils, the toes and rarely the throat.[8]

General

Chromium metal itself is stable and relatively non-toxic because of its insolubility in water and body fluids.[8] Chromium, a trace element essential for sugar and fat metabolism, is necessary for the action of insulin.[8] Chromium deficiency in the diet of animals causes a syndrome simulating diabetes. A lack of chromium has also been associated with arteriosclerotic heart disease, elevated cholesterol levels in the blood, and high fat content of the aorta. In areas where arteriosclerosis is mild or absent, more chromium is found in body tissue than where the disease is endemic.[a]

The toxic dose of chromium for man is reported by Rothstein to be about 0.5 g $K_2Cr_2O_7$.[5] The toxicity of chromium salts toward aquatic life varies with the species, temperature, pH, valence of the chromium, and synergistic or antagonistic effects, especially that of hardness.[5] Fish are relatively tolerant of chromium salts, but lower forms of aquatic life are extremely sensitive. There appears to be no evidence to lead to a conclusion that hexavalent chromium is more toxic toward fish than the trivalent form. Toward fish and other aquatic organisms the toxicities of trivalent and hexavalent chromium compounds have been reported as follows[5]:

Concentration of Chromium mg/liter	Compound Used	Type of Organisms	Remarks
52	$K_2Cr_2O_7$	Young eels	Tolerated for 50 hours
5.2	$K_2Cr_2O_7$	Brown trout	Toxic
20	$K_2Cr_2O_7$	Rainbow trout	Toxic at 18° C
1.2	$Cr_2(SO_4)_3$	Sticklebacks	Lethal limit
2.0	$Cr_2(SO_4)_3$	Sticklebacks	Survived only 2 days
5.2	$KCr(SO_4)_2$	Young eels	Survived an average of 18.7 hours
0.05	------	Daphnia magna	Killed in 6 days
0.21	$K_2Cr_2O_7$	Protozoan (Microregma)	Threshold effect
1.4	Na_2CrO_4	Gammarus pulex	Total mortality
40.6	$K_2Cr_2O_7$	Snail	Hardwater TL_m, 20° C
0.7	$K_2Cr_2O_7$	E. coli	Threshold effect
148	CrO_4	Polycelis nigra	Toxic threshold

Towards mammals the effects of hexavalent chromium have been reported as follows: [15]

Animal	Route	Material	Average Dose or Concentration	Duration	Effect
Rabbit & Cat	IH	Chromates	1-50 mg/m³	14 hr/day for 1-8 months	Pathologic changes in lungs
Rabbit	SC	$K_2Cr_2O_7$	20 mg	--	Lethal
Rabbit	IV	$K_2Cr_2O_7$	0.7 cc of 2% solution/kg body wt.	--	Fatal
Mouse	IH	Mixed dust containing	7 mg/m³ as CrO_3	37 hours over 10 days	Fatal
Mouse	IV	Zinc chromate	0.75 mg	1 dose	Fatal
Mouse	IV	$K_2Cr_2O_7$	0.7 cc of 2% solution per kg body wt.	--	Fatal
Dog	IV	$K_2Cr_2O_7$	210 mg as Cr	--	Rapidly fatal
Dog	SC	$K_2Cr_2O_7$	210 mg as Cr	--	Rapidly fatal

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*IH - inhalation; IV - intraveneous; SC - subcutaneous.

Chromium is present in trace amounts of soils and in plants, but there is no evidence that chromium is essential or beneficial for plant nutrition.[19] Sedora reported that concentrations of trivalent or hexavalent chromium in excess of 1.0 mg/kg of soil inhibited nitrification. On the other hand, the addition of 5 mg of chromium per kg of soil resulted in a slight increase of the nitrogen content of peas. Chromium is picked up by plants from the soil, for vegetables grown on soil irrigated with waste waters containing chromium had 3-10 times more chromium than those those grown in similar soil devoid of chromium containing irrigation water.[19]

C. Environmental Properties

The drinking water standard is 0.05 mg/liter for hexavalent chromium[5]; the recommended standard for trivalent chromium is likewise 0.05 mg/liter.[6] The chromium containing sludges when occurring as a result of the standard reduction/hydroxide precipitation treatment methods can present a twofold toxicological hazard if landfilled.[6] The sludges can contain soluble chromium salts and complexes which, if leached out of the fill, can be detrimental. It is also possible for acid species to be landfilled with the hydroxide sludges, dissolve them, forming water soluble chromium compounds. Those water soluble materials can find their way to a potable water table from an inadequately placed landfill site.[6]

D. Radioactive Properties

None

Copper and Its Oxides

A. Physical/Chemical Properties

Copper (Cu)

Elemental copper (at. wt. 63.54 g, m.p. 1083° C, b.p. 2595° C, d. 8.94)[9] dissolves readily in nitric and hot concentrated sulfuric acid; it solubilizes slowly in hydrochloric and dilute sulfuric acid but only when exposed to the atmosphere.[1] Copper is more resistant to atmospheric corrosion than iron, forming a green layer of hydrated basic carbonate. It is noncombustible except as powder. Metallic copper is insoluble in water.

Cuprous Oxide (Cu_2O)

Copper (I) oxide (m. wt. 143.08 g, m.p. 1232° C, b.p. 1800° C, $d.^{25}$ 6.0)[9] exists as octahedral crystals or microcrystalline powder, the color varying from yellow, red or brown, depending on the method of preparation and the particle size.[1] This oxide is stable in dry air but gradually oxidizes to CuO in moist air. It is insoluble in water and alcohol but soluble in hydrochloric acid, ammonium chloride, ammonium hydroxide and slightly soluble in nitric acid.

Cupric Oxide (CuO)

Copper (II) oxide (m. wt. 79.54 g, m.p. 1326° C, d. 6.3-6.49)[9] occurs as a black to brownish-black amorphous or crystalline powder or granules. It is soluble in dilute acids, alkali cyanides and $(NH_4)2CO_3$ solutions; it is slowly soluble in ammonia.[1] Cupric oxide is slightly soluble in water; at a pH 9 it solubilizes to a concentration of 1.54×10^{-5} mg/liter as Cu^{++} in pure water.[20] As the pH decreases, the solubility of cupric oxide increases such that at pH 5 its saturation concentration is 313.0 mg/liter as Cu^{++}.

B. Biological Properties

Copper if found in traces in all plant and animal life; it is believed to be essential for nutrition.[5] The physiological function of copper appears to be involved in the metabolism of iron, for the utilization of iron by the blood-forming organs does not occur properly in the absence of copper. The copper requirement is reported to be about 2 mg/day for children and 3 mg/day for adults.

In general, the soluble ionized salts of copper are much more toxic than the insoluble or slightly dissociated compounds.[a] Probably the most poisonous salts are the chloride and the subacetate. Cuprous chloride is said to be twice as toxic as the more common cupric salt, but no major toxicological distinctions are recognized between the two valence states of copper. As the sublimed oxide, copper may be responsible for one form of metal fume fever. Inhalation of copper dust has caused, in animals, hemolysis of the red blood cells, deposition of hemofusion in the liver and pancreas, and injury to the lung cell; injection of the dust has caused cirrhosis of the liver and pancreas, and a condition closely resembling hemochematosis, or bronzed diabetes. However, considerable trial exposure to copper compounds has not resulted in such disease.

As regards local effect, copper chloride and sulfate have been reported as causing irritation to the eye and upper respiratory tract. Discoloration of the skin is often seen in persons handling copper, but this does not indicate any actual injury from copper.

Copper resembles many other heavy metals in its systemic toxic effects: widespread capillary damage, kidney and liver injury, and central nervous excitation followed by depression.[a] Hemolytic anemias are described in acute poisoning in man and chronic poisonings in sheep. Copper appears to be less deleterious than most heavy metals when ingested continuously in small amounts, but chronic feeding to animals results in a pigmentary cirrhosis of the liver.

Acute poisoning from the ingestion of copper salts is rarely severe, if the metal is removed promptly by emesis.[a] Vomiting is provoked chiefly by the local irritant and astringent action of ionic copper on the stomach and intestines. If vomiting fails to occur, gradual absorption from the bowel may cause systemic copper poisoning. Death is delayed for several days and apparent recovery may be followed by a fatal relapse.

A type of chronic copper poisoning in man is recognized in the from of a metabolic disease called hereditary hepatolenticular degeneration (Wilson's disease).[a] Tissue copper levels are elevated in Wilson's disease, and this accumulation has been noted to precede the development of liver pathology, which may ultimately prove fatal. If dietary copper intake is reduced and urinary excretion promoted, the neurologic signs and symptoms associated with Wilson's disease are alleviated. BAL, calcium disodium edetate and sulfur-containing amino acids can mobilize tissue copper stores for excretion; at least BAL has been shown to produce some clinical improvement, but repeated injections frequently give rise to undesirable side effects.

Because copper in concentrations high enough to be dangerous to human beings renders water disagreeable to taste, it is believed by some that copper is probably not a hazard in domestic water supplies; although in excessive quantities it has been found toxic to a wide variety of aquatic forms, from bacteria to fish. The toxicity of copper to aquatic organisms varies significantly not only with the species, but also with the physical and chemical characteristics of the water such as its hardness, temperature, turbidity and carbon dioxide content.[5] In hard water, the toxicity of copper salts is reduced by the precipitation of copper carbonate or other insoluble compounds. Ellis has found that the toxicity of copper to fish varies greatly depending on the presence of magnesium salts and phosphates. In the control of Chironomus larvae, copper and chlorine together act synergistically to increase the toxicity of each acting alone. The sulfates of copper and zinc and of copper and cadmium are synergistic in their toxic effect on fish. Synergism also exists between copper and mercury and between copper and pentachlorphenate. On the other hand, sodium nitrite and sodium nitrate have been reported to decrease the toxicity of copper sulfate to fish, and copper has shown evidence of decreasing the toxicity of cyanide.

C. Environmental Properties

The water quality standard for copper and its oxides is 1.0 mg/liter as Cu.[5]

Many copper salts are highly soluble as cupric or cuprous ions.[5] Copper salts occur in natural surface waters only in trace amounts, up to about 0.05 mg/liter so that their presence is generally the result of pollution, attributable to the corrosive action of the water on copper and brass tubing, to industrial effluents, or frequently to the use of copper compounds for the control of undesirable plankton organisms. The chloride, nitrate and sulfate of divalent copper are readily soluble in water, but the carbonate, hydroxide, oxide and sulfide are not. Indeed, cupric ions introduced into natural waters at pH 7 or above will quickly precipitate as the hydroxide or as basic carbonate, $CuCO_3 \cdot Cu(OH)_2 \cdot H_2O$, to be removed by absorption or sedimentation. As a result, copper ions are not likely to be found in natural surface waters or ground water.

Tobia and Hanna investigated the chemical fate of copper salts in the soil, especially with respect to organic matter and carbonate content of the soil.[5] They found that when copper sulfate was added to irrigation water at a concentration of 20 mg/liter, it reached an equilibrium in the soil at 1.0 mg/liter after 6 hours at 20° C. Copper retention in the soil appeared to be correlated more with organic matter and soil alkalinity than with the clay content of the soil, and organic matter appears to be more effective than carbonates in retaining copper.

One of the problems with heavy metals is their tendency to concentrate through both aquatic and terrestrial food chains. Aquatic macro- and micro-flora and fauna accumulate heavy metals, such as copper, in body tissues in significantly greater concentrations than present in the surrounding environment. Important mechanisms for uptake of copper and other heavy metals include: absorption from the soil and sediments by plants, ingestion by stream bottom feeders and by detrius feeders. The aquatic macro- and micro-flora and fauna are the food source for fish insects which retain the copper in the tissues of the consumed organisms. The fish and insects are consumed in turn by larger organisms; this process continues to the organisms at the top of the pyramidal food chain, such as man and large carnivorous birds and mammals. The more links in the chain, the more severe the bioaccumulation phenomenon.

D. Radioactive Properties

None

Lead and Its Compounds

A. Physical/Chemical Properties

Lead (Pb)

Elemental lead (at. wt. 207.19, m.p. 327.4° C, d. $^{20}_{4}$ 11.34) is a bluish-white, silvery, gray metal.[1] It is highly lustrous when freshly cut but tarnishes upon exposure to air.[1] Because of lead's softness and malleability it can be easily melted, cast, rolled and extruded.[1] Lead is soluble in hot concentrated nitric acid, in boiling concentrated hydrochloric or sulfuric acid, and in acetic acid. Lead is attached by pure H_2O and weak organic acids in the presence of oxygen but is resistant to tap H_2O, hydrofluoric acid, brine and solvents.[1]

Lead Carbonate ($PbCO_3$)

Lead carbonate (m.w. 267.20, m.p. (dec) 315° C, d. 6.6)[9] exists as white, powdery crystals which are soluble in acids and alkalis, e.g., acetic acid or dilute nitric acid with effervescence.[1] Neutral lead carbonate is insoluble in ammonia, alcohols and practically insoluble in water (solubility at 20° C 0.0017 g/liter).[9] Neutral lead carbonate is usually accompanied by the impurity basic lead carbonate.

Basic Lead Carbonate ($2PbCO_3$ $Pb(OH)_2$)

This lead carbonate (m.w. 775.60, m.p. (dec) 400° C, d. 6.86)[9] is a white amorphous powder which is soluble in acids (especially nitric acid), slightly soluble in aqueous CO_2 and insoluble in alcohols.[4] Basic lead carbonate solubilizes to the extent of 1.1-1.7 mg of $PbCO_3$/liter at 20° C.[9]

Lead Sulfate ($PbSO_4$)

Lead sulfate (m.w. 303.28, m.p. 1170° C, d. 6.12-6.39)[9] is a white rhombic crystal with water solubilities of 42.5 mg/liter (25° C), 28 mg/liter (0° C) and 56 mg/liter (40° C).[9] It is slightly soluble in concentrated H_2SO_4 but is insoluble in most acids. Lead sulfate is soluble in ammonium salts.[9]

Lead Monoxide (PbO)

Lead monoxide (m.w. 223.21, m.p. 888° C, d. 9.53, b.p. 1472° C)[20] consists of a yellow to yellowish-red, heavy, odorless powder or minute tetragonal crystalline scales.[1] At 300-450° C in the air it is converted into Pb_3O_4 but at higher temperatures it reverts back to PbO.[1] Lead monoxide is insoluble in alcohol but is soluble in acetic acid, dilute HNO_3, ammonium chloride, strontium chloride and in warm solutions of fixed alkali hydroxides.[1] Its solubility in water is 17.0 mg/liter.[9]

Lead Dioxide (PbO_2)

Lead dioxide (m.w. 239.21, m.p. (dec) 290° C, d. 9.375)[9] consists of dark brown hexagonal crystals[3] which evolve oxygen when heated, first forming Pb_3O_4 and at high temperatures PbO.[1] This lead oxide is soluble in glacial acetic acid[4], in dilute HCl with the evolution of Cl_2[1], in dilute nitric acid in the presence of H_2O_2[1] in alkali iodine solutions with the liberation of iodine and in oxalic acid or other reducers.[1] Lead dioxide is insoluble in water and alcohol. It is an oxidizing agent and hence, reacts with reducing material; it is a dangerous fire risk in contact with organic materials.[4]

Lead Hydroxide ($Pb(OH)_2$)

Lead hydroxide (m.w. 241.20, m.p. (dec) 145° C, d. 7.592)[9] exists as a white bulky powder[4] which is soluble in alkalis, nitric or acetic acid and fixed alkali hydroxides.[1] Its solubility at pH 9 is 8.54 mg Pb^{++}/liter and at pH 7 is 150.0 Pb^{++}/liter, and as the pH decreases further lead hydroxide's solubility increases by more than an order of magnitude.[20] It absorbs CO_2 from the air and decomposes at 14.5° C.[4]

B. Biological Properties

The toxicity of the various lead compounds appears to depend upon:[3]

(a) the solubility of the compound in the body fluids;

(b) the fineness of the particles of the compound, solubility being greater in proportion to the fineness of the particles;

(c) conditions upon which the compound is being used; where a lead compound is used as a powder, contamination of the atmosphere will be much less where the powder is kept damp.

The solubility of some of the lead compounds in the blood serum at 25° C in mg/liter are:[24]

PbO	1152.0
Pb	578.0
$PbSO_4$	43.7
$PbCO_3$	33.3

Lead is poisonous in all forms. It is one of the most hazardous of the toxic metals because the poison is cumulative and toxic effects are many and severe.[2] Of the various lead compounds, the carbonate, monoxide and sulfate are considered to be more toxic than elemental lead or other lead compounds. The toxicity of lead chromate is less than would be expected, due to its low solubility. All of the lead compounds are sufficiently soluble in digestive juices to be considered toxic.[2]

In soft H_2O, lead may be very toxic whereas in hard H_2O equivalent concentration of 50 mg/liter has destroyed the toxic effect of 1.0 mg/liter of lead.[5] Immunity to lead cannot be acquired and sensitivity to lead seems to increase with exposure.

Lead may enter the human system through inhalation, ingestion or skin contact.[6] Direct skin contact is of negligible importance in connection with inorganic lead compounds. However, in the case of organic lead compounds, skin contact can be a real hazard. Industrially, inhalation of dust, mist or fumes, is the chief method by which lead and its inorganic compounds may enter the body.[6]

Lead poisoning is rated as 10 times more liable to occur from breathing lead dust than from swallowing it.[24] This is probably due to the fact that the liver filters out swallowed substances like lead and removes them from the blood before harm can be done. If they are breathed, they are taken up by the blood stream, pumped all over the body and thus make themselves felt more readily than would otherwise be possible. Lead is thought to be toxic only when present in the systemic circulation. Thus it can be stored by the body and only becomes a danger when it is returned to circulation in greater amounts than the body can safely eliminate.[24]

Following ingestion of a large amount of any insoluble lead salt (especially the acetate, carbonate or chromate), the signs and symptoms are due largely to local irritation of the alimentary tract.[2] If absorption is sufficient, pain, leg cramps, muscle weakness, paresthesias, depression, coma, and death may follow within 1 or 2 days. Three clinical syndromes are recognized in the diagnosis of chronic plumbism:[2]

(a) The alimentary type is characterized by anorexia, a metallic taste, constipation and severe abdominal cramps (lead colic due to intestinal spasm).

(b) The neuromuscular type is characteristic of adult plumbism which consists of peripheral neuritis limited to the extensor muscles. Weakness or paralysis may occasionally be accompanied by arthralgia and myalgia, but sensation is otherwise unaffected. As produced in laboratory animals a decrease in motor nerve conduction velocity is associated with segmental demyelination.

(c) The cerebral type of lead poisoning (lead encephalopathy) is the most common type in children. Encephalopathy is a complication in about 50 percent of lead poisoning cases and the mortality rate among patients developing cerebral involvement in about 25 percent.[2]

The daily intake of lead in food and beverages is approximately 0.3 mg which the human body is capable of eliminating daily. However, if more lead is ingested than excreted (0.3-1.0 mg/day)[6] a condition exists which is referred to as "chronic lead poisoning", which may develop within weeks or months.[6] Many acute poisonings, however, subside without sequelae, since the absorption of lead from the bowel is inherently slow and incomplete.[2] Presumably this outcome is also favoured by vigorous treatment. As long as the body, however, contains excessive amounts of lead fixed in the tissues, symptomatic recurrences are an ever present threat. In all recurrent episodes there is a characteristic rise in the lead concentration of the body fluids and excreta.[2] A lead content in blood greater than 0.005 percent and in urine greater than 0.08 mg/liter support a diagnosis of lead poisoning.[2]

Lead accumulates in bones, where it replaces calcium.[8] Bones store almost one half of the total body pool, with long bones (arms and legs) accumulating about 3 times more than flat bones (breast bone, vertebrae). Becker and coworkers found 5 ppm lead in ancient bones 500 years old in comparison with 50 ppm which is present in bones today. They implicated contemporary air pollution as the primary cause of this increase.[8] With advancing age, some of the metabolized lead accumulates in soft tissues. Newly absorbed lead is retained in the body as lead triphosphate, especially in liver, kidneys, pancreas, and aeorta.[8]

Plants growing on soils containing 1 ppm of lead have shown 20-25 ppm lead per gram in their ash. Samples taken from different portions of a plant vary considerably in their lead content.[8]

It is thought that inorganic lead salts in irrigation water may be toxic to plants although toward giant kelp, Macrocystis pyrifera, lead was found to be less toxic than Hg, Cu, Cr^{+6}, Zn and Ni.[5] Lead nitrate produced no deleterious effects on the rate of photosynthesis of kelp in sea H_2O during a 4-day exposure at 4.1 mg Pb/liter.[5]

C. Environmental Properties

The water quality standard for all lead compounds is 0.05 mg/liter as lead.[6] The solubilities of all lead compounds discussed in this report fall above this concentration: $Pb(OH)_2$, 150 mg/liter; PbO, 64 mg/liter; $PbSO_4$, 42 mg/liter; $PbCO_3 \cdot Pb(OH)_2$, 1.1-1.7 mg/liter; $PbCO_3$, 1.7 mg/liter; $PbCrO_4$, 0.1 mg/liter, therefore, surface disposal or landfilling procedures must provide for adequate protection of surface and ground waters. Disposal by landfill techniques in a California Class I type disposal site would be adequate providing a "California type" climate exists; in other areas protection would need to be more rigorous.

Under certain conditions lead is solubilized as either the chloride or the sulfate which are both slightly soluble and hence landfill disposal of lead is not recommended under certain conditions.[6] The characteristics of water, soft or hard, that appear to be conducive to plumbo-solvency, include comparative absence of calcium and magnesium bicarbonates, low pH, high dissolved oxygen, and high nitrate content.

One of the problems with heavy metals is their tendency to concentrate through both aquatic and terrestrial food chains.[2c] Aquatic macro- and microflora and fauna accumulate heavy metals such as lead in body tissues in significantly greater concentrations than present in the surrounding environment. These organisms are the food source for fish and insects which retain the heavy metals in the tissues of the consumed organisms. The fish and insects are consumed in turn by larger organisms, this process continues to the organisms at the top of the pyramidal food chain, such as man and large carnivorous birds and mammals. The more links in the chain, the more severe the bioaccumulation phenomenon.

For lead and its compounds, this bioaccumulative phenomenon is less acute. Lead accumulates in the bones (and/or exoskeleton) of animals in somewhat greater proportions than in other tissues.[8] Since the bones and exoskeleton of most larger animals are not consumed, the lead contained therein is not available to top carnivores. Also lead compounds tend to interact with soil particles to form complexes which are not readily available to plant uptake. Although plants do accumulate lead from soil and because lead is translocated poorly, it tends to remain in the roots and return to the soil when the plant dies. Leaves readily accumulate airborne lead compounds in the leaf tissue, and most of the lead will still be in the leaves when they are consumed by other organisms.

D. Radioactive Properties

None

Nickel and Its Compounds

A. Physical/Chemical Properties

Nickel (Ni)

Elemental nickel (at. no. 28, m.w. 58.71, d. 8.908, m.p. 1453° C, b.p. 2732° C, v.p. 1 mm at 1810° C)[9] is a hard, lustrous, silver-grey ferromagnetic metal which crystallizes in face-centered cubes.[1] Its electrical resistivity is 6.844 microhms-cm at 20° C.[1] Nickel is malleable and is readily fabricated by hot- and cold-working.[4] It is corrosion resistant at ordinary temperatures, and burns in oxygen forming NiO. The solubility of elemental nickel in pure water at 20° C is 12.7 mg/liter;[20] it is soluble in dilute nitric acid, slightly soluble in hydrochloric and sulfuric acids, and insoluble in ammonia and strong alkalis.[4]

Nickel Hydroxide ($Ni(OH)_2 \cdot nH_2O$)

Nickelous hydroxide (m.w. 92.7, d. 4.1, m.p. (dec) 230° C)[9] is composed of light green crystals[3] or an amorphous apple-green powder.[1] When ignited in air at about 400° C nickelous hydroxide absorbs oxygen and is converted to black nickelic oxide (Ni_2O_3).[1] $Ni(OH)_2$ is soluble in dilute acids and ammonia.[1] Its solubility in water is pH dependent. At a pH of 7, the solubility of $Ni(OH)_2$ is about 135 mg/liter. Solubility decreases as pH increases until pH 10.3, the pH at which $Ni(OH)_2$ is least soluble (11.7×10^{-4} mg/liter (theoretical value)]; above pH 10.3 the solubility increases.[20] The solubility of $Ni(OH)_2$ increases the pH in acidic solutions, and is approximately two orders of magnitude more soluble in water at pH 5 that at pH 7.[20] Other ions in solution affect the solubility of $Ni(OH)_2$. In HCl solutions solubility is decreased by about a factor of ten. In H_2SO_4 solutions the solubility is increased by a factor of 5.[20]

B. Biological Properties

Nickel occurs naturally in the blood in two forms: an ultrafilterable fraction and a protein bound fraction, which together account for 87 to 89 percent of the nickel in man.[18] A dietary requirement for Ni has not been determined. Nickel ions can replace calcium ions in the generation of action potentials in muscle, but the duration of the potential is increased.[18]

Nickel and its compounds in high doses have produced cancer of the sinuses and of the lungs in nickel workers in Wales and Ontario.[8] Furnace workers with more than three years of exposure had a death rate 200 times higher than expected. The disease may not develop for 22 years after exposure. However, nickel cannot be considered the exclusive cause of cancer in these cases because of the simultaneous presence in the atmosphere of other air-borne poisons, particularly arsenic and fluoride. Nor has it been determined to what extent the population near such establishments has been affected by the metal.[8]

Partly because of local astringent and irritant actions, nickel salts act as emetics when swallowed (but also by other routes).[2] As with other irritant-emetics, the lethal dose is presumed to vary widely. Although absorption of nickel and most of its salts from the intestines is poor, sufficient quantities are absorbed to cause systemic responses. These include capillary damage (especially in the brain and adrenals), renal injury, myocardial weakness, and central nervous depression. Pulmonary effects are predominant after a respiratory exposure to gaseous nickel carbonyl.[7] Injection of large doses of Ni, as a Ni compound (1-3 mg/kg body weight) has been shown to cause internal disorders, convulsions and asphyxia in dogs.[3]

Nickel dermatitis can be induced in humans through contact with nickel-plated articles, industrial exposures to nickelous dusts or baths or internal exposure to nickel.[18] The symptoms compose two levels: (1) a simple dermatitis at the area of contact, the typical "nickel itch", consisting of burning and itching of the exposed skin. There is marked variation on individual susceptibility to the dermatitis. It occurs more frequently under conditions of high temperature and humidity when the skin is moist, and chiefly affects the hands and arms; and (2) a chronic eczematous reaction, in which erythema occurs, and later nodules, which may eventually form pustules, appear in the web of the fingers and the forearm.[18]

In many green plants, degree of absorptions of Ni by the roots appears to be dependent upon the soil pH.[18] Raising the pH of serpentine or high nickel solids by the addition of lime usually somewhat alleviates the toxic effects of nickel. The excessive absorption of nickel is thought to reduce the cation exchange capacity of roots in such diverse plants as oats, beans, peas, sunflowers, and tomatoes.[18] Nickel is extremely toxic to citrus plants.[5] It is found in many soils in California, generally in insoluble form but excessive acidification of such soil may render the nickel compounds soluble, causing severe injury or death of plants.[5]

C. Environmental Properties

The provisional limit in water and soil for nickel and its compounds is 0.05 mg/liter.[8]

Little information concerning accumulation in organisms, magnification in food webs and mechanisms of transport throughout the environment is available for nickel and its compounds. The biomagnification phenomena which involves most heavy metals appears to be effective for nickel as well, with the major exception that plants are so sensitvie to Ni that relatively little is accumulated before its toxic effects result in the death of the plant.

D. Radioactive Properties

None

Mercury and Its Compounds

A. Physical/Chemical Properties

Elemental Mercury (Hg)

Mercury (at. wt. 200.59, m.p. −38.89° C, b.p. 356.9° C, v.p. 1 mm at 126.2° C, d^{20}_{4} 13.5939)[9] is a silver-white, heavy, mobile, liquid metal which is slightly volatile at ordinary temperatures[1]; with every degree rise in temperature its volatility rises 10 percent.[8] It is insoluble in hydrochloric acid, water, alcohol and ether but is soluble in sulfuric acid upon boiling and readily soluble in nitric acid.[4] Mercury has an extremely high surface tension engendering it with unique rheological behavior.[4] This metal is converted by heating with concentrated H_2SO_4 into mercurous or mercuric sulfate (depending on the excess of the acid at the time of heating).[1] When pure, mercury does not tarnish on exposure to air at ordinary temperature, but when heated to near the boiling point, mercury slowly oxidizes to HgO.[1]

Mercuric Chloride ($HgCl_2$)

Mercuric chloride (m.w. 271.52, d. 5.4, m.p. 277° C, b.p. 302° C[9]) is a white substance which occurs as crystals, granules, or powder.[1] $HgCl_2$ volatilizes unchanged at about 300° C, it is slightly volatile at 25° C and appreciably so at 100° C.[1] Its solubility in water is 69.0 g/liter at 20° C and 480 g/liter at 100° C[9]; the pH of a 0.2 molar aqueous solution is 2.2.[1] $HgCl_2$ is amphoteric; therefore, its solubility is increased by HCl or alkali chlorides. $HgCl_2$ is soluble in alcohol (very soluble in hot alcohol), benzene, ether, glycerol and acetic acid.[1]

Mercuric Oxide (HgO)

Mercuric oxide (m.w. 216.61, d. 11.14, m.p. (dec) 500° C[1]) is soluble in water as follows: 53 mg/liter at 25° C, 395 mg/liter at 100° C.[9] It exists in two forms, red and yellow.

Red mercuric oxide is a heavy, bright red or orange-red, odorless, crystalline powder or scales. Its color is yellow when finely powdered. HgO (red) decomposes into its elements when exposed to light[1] or when heated to 500° C[3]. At 400° C it becomes dark red-black but becomes red again upon cooling. Amphoteric HgO (red) is soluble in dilute HCl or HNO_3 and solutions of alkali cyanides or alkali iodides; it is slowly soluble in alkali bromides, and insoluble in alcohol.[1]

Yellow mercuric oxide is an odorless, amorphous yellow to orange-yellow powder[3] which turns red when heated; the yellow color returns after cooling[1] which decomposes to its elements at 500° C.[3] It is stable in air but turns dark upon exposure to light.[4] Other physical properties and solubilities are the same as those of the red form, but the yellow form is more reactive because the particles are more finely divided.[1]

Mercurous Sulfate (Hg_2SO_4)

Mercurous sulfate (m.w. 497.24, d. 7.57) is a white to yellow crystalline powder which decomposes when heated[4] and becomes gray on exposure to light.[1] Hg_2SO_4 is soluble in nitric and sulfuric acids; its solubility in water is 600 mg/liter at 25° C and 900 mg/liter at 100°C.[9]

Mercuric Sulfide (HgS)

Mercuric sulfide (m.w. 232.68, sp. gr. 8.06-8.12, m.p. (sub) 583.5° C)[9] (Red: Hg-86.22%, S-13.78%) precipitates out as a bright scarlet-red powder or hexagonal red crystals which blacken on exposure to light, particularly in the presence of water or alkali hydroxides.[1] When it is ignited in air it decomposes into elemental Hg and sulfur, the latter burning to SO_2.[1] Mercuric sulfide is practically insoluble in water (at 18° C, solubility is 1.25×10^{-5} g/liter) and alcohol but is soluble in aqua regia with separation of sulfur in warm hydriodic acid with the evolution of H_2S.[1]

Other Mercury Salts

When heated with Na_2CO_3, mercury salts yield metallic Hg and are reduced to metal by H_2O_2 in the presence of alkali hydroxide.[1] Soluble ionized mercuric salts give a yellow precipitate of HgO with NaOH and a red precipitate of HgI_2 with alkali iodide.[1] Mercurous salts give a black precipitate with alkali hydroxides and a white precipitate of calomel with HCl or soluble chlorides. They are slowly decomposed by sunlight.[1]

B. Biological Properties

General

Mercury is a cumulative protoplasmic poison; after absorption it circulates in the blood and is stored in the liver, kidneys, spleen and bone. It is eliminated in the urine, feces, sweat, saliva and milk. Adequate evidence now exists to ascribe differences among various forms of mercury poisoning to differences in the biological distribution and excretion of the causitive agents and their metabolites.[3] E.g. respiratory exposure to mercury vapor results in the retention of high initial concentrations in the lungs. A large proportion of this lung burden is absorbed and gradually cleared. Transiently, high concentrations are said to exist in the brain and may be related to the high incidence of central nervous system signs seen after this type of exposure. The kidneys, however, eventually accumulate the greatest proportion of the total body burden.[7]

Mercury poisoning may be acute or chronic with the latter being the more prevalent of the two types. Symptoms and signs involving the central nervous system are those most commonly seen in chronic poisoning of inorganic mercury, the principal features of which are tremors and psychological distrubances.[3] Intoxication from mercury vapor or from absorption of mercuric salts may be due, in both cases, to the action of the mercuric ion.[6] Metallic mercury vapor is able to diffuse much more extensively into the blood cells and various tissues than inorganic mercury salts, but once distributed, most of it is oxidized to the mercuric form. In most cases of industrial exposure to mercurials, symptoms of mercury poisoning were observed only among workers who had been exposed to mercury levels above 100 micrograms/M^3 in air.[8]

Elemental Mercury

Metallic mercury constitutes a special case in the toxicology of mercury compounds since dangerous symptoms are recognized only after inhalation or prolonged skin contact.[7] In respiratory exposures, Hg vapor diffuses through the alveolar membrane and reaches the brain where it interferes with coordination; severe nonproductive cough and dyspnea sometimes precede symptoms of systemic mercury poisoning.[7] Inhalation of mercury in concentrations of 1200–8500 micrograms/M^3 in air results in acute intoxication, affecting primarily the digestive system and kidneys, and is characterized by a metallic taste, nausea, abdominal pain, vomiting, diarrhea, headache and sometimes albuminuria.[6] After a few days the salivary glands swell, stomatitis and gingivitis develop, and a dark line of mercuric sulfide forms on the inflamed gums. Death as a result of extreme exhaustion frequently occurs with poisoning of this degree of severity.[6]

Inorganic Mercury

The action of inorganic mercury differs considerably from that of organic methyl mercury.[8] Inorganic mercury usually settles in and damages the liver and kidneys, especially the kidney tubules (the portion of the nephron involved in reabsorption of of vital agents from the urine). In the small intestines it accounts for diarrhea. Mercury vapor diffuses readily through the alveolar membrane and reaches the brain, where it interferes with coordination.[6]

Organic Mercury

The discovery of the facile, biological conversion of mercury and its compounds to methyl mercury have brought into question the wisdom of any large scale use of mercury and its inorganic and organic compounds.[6]

Organic mercury compounds may enter the body by inhalation, skin absorption or ingestion.[6] There is evidence that inhalation of organic mercury vapor and aerosols may be more detrimental than the other means of entry since absorption through the respiratory tract leads to a higher rate of accumulation of mercury in the brain.[6]

The toxicologic effects of organomercurials are strongly influenced by the nature of the organic portion of the molecule.[6] Short chain alkyl mercury compounds (e.g., methyl and ethyl mercury) are relatively stable in the body and may circulate for a long time unchanged in the blood; methyl mercury has a biological half-life in man of about 70 days. The stability of the alkyl mercurials, particularly methyl mercury, favors their accumulation in the body where they are found principally in the brain. Thus, more than 98 percent of the mercury found inthe brain is in the form of methyl mercury.[6]

Aromatic mercury compounds, methoxyalkyl mercurials and most other organic mercury compounds are degraded to inorganic mercury in the body.[6] Therefore, the physiological and toxicological behavior of the nonalkyl organomercurials resembles that of inorganic mercury compounds, with preferential accumulation in the kidneys and more rapid excretion than the short chain alkyl analogs.[6]

The symptomatology of acute and chronic poisoning from methyl and ethyl mercury is similar; including numbness and tingling of the lips or hands and feet, ataxia, disturbances of speech, concentric constriction of the visual fields, impairment of hearing, and emotional disturbances.[6] With severe intoxication the symptoms are irreversible. Children born to mothers with exposure to large amounts of methyl mercury exhibited mental retardation and also cerebral palsy with convulsions.[6]

Because so few cases of toxicity have appeared from phenyl mercurials exposure, even to high levels in air over a period of years, it is apparent that these compounds are low in toxicity relative to other forms of mercury.[6] Clinical and experimental evidence suggests that a similar conclusion is applicable to methoxyethyl compounds.

Toxicity of Hg Compounds Towards Aquatic & Terrestrial Life

The lethel concentrations of mercury compounds for various aquatic organisms have been summarized in a 1970 U. S. Geological Survey Report.[6] For mercuric chloride, the lethal concentrations in ppb are: E. coli (bacteria), 200; Schendismus (phytoplankton), 30; Microregma (protozoa), 150; Daphnia magna (zooplankton), 6; Marinogammarus marinus (amphipod), 100; Polycelis nigra (flatworm), 270; Bivalve larvae (Mollusca), 27; Stickleback (fish), 4-20; Guppy (fish), 20; Eel (fish), 27; Rainbow trout (fish), 9200. The lethal dose of mercuric chloride for rats is 37 mg/kg body weight.[7]

For mercuric nitrate, the lethal concentrations in ppb are: Guppy, 20; Stickleback, 20; Mericierella enigmatica (polychaete), 1000; Mesospheroma oregonesis (isopod), 15. The lethal dose for mice is 4 mg/kg body weight.[6]

No toxicity data were found for Hg, $HgSO_4$ or mercuric diammonium chloride. Mercuric sulfate decomposes in cold water into a yellow insoluble basic sulfate and free H_2SO_4, and both Hg and mercuric diammonium chloride are insoluble in cold water. It is to be noted, however, that Hg and all inorganic Hg compounds discharged into the aquatic environment could eventually be biologically converted into the more toxic methyl Hg by anerobic microorganisms, which can then be taken up by living aquatic organisms.[6]

C. Environmental Properties

The U.S. Drinking Water Standards for Mercury and Its Compounds is summarized in the following table:[6]

Contaminant in H_2O and Soil	Provisional Limits
Mercury	0.005 ppm
Mercuric chloride	0.005 ppm as Hg
Mercuric nitrate	0.005 ppm as Hg
Mercuric sulfate	0.005 ppm as Hg
Mercuric diammonium chloride	0.005 ppm as Hg

Through the food chain mercury becomes more concentrated as it is taken up by various links; mercury penetrates the surface of plankton by passive absorption.[8] In contrast, fish takes up methyl mercury both through consumption of food, mainly plankton, and through their gills. Fish that breathe faster and eat more than other species, such as the tuna, concentrate more mercury in their bodies during their lifetime than other fish. The older the fish, the greater is the mercury concentration in its body. The metal accumulates in its body fats. A long retention time in some fish (mercury's half-life is 200 days) accounts for added accumulation. Birds that eat fish concentrate even more mercury in their body. Whales and seals have been found to contain very high levels of mercury.[8]

A terrestrial bioaccumulation of mercury also occurs. Mercury is accumulated by growing plants, it is absorbed through leaves and roots and is subsequently transmitted to the remainder of the plant.[8] Rodents and ungulates accumulate mercury from the plants, and carnivores feeding on these animals accumulate even more mercury. Therefore, the organisms at the top of the food chain tend to accumulate the greatest amounts of mercury.

D. Radioactive Properties

None

Silver

A. Physical/Chemical Properties

Silver (at. wt. 107.87, m.p. 960.5° C, b.p. 2212° C, d. 10.5)[9] is a soft, ductile and malleable, lustrous white solid[4] with a face-centered cubic structure.[1] It resists oxidation, but tarnishes in air through reaction with atmospheric sulfur compounds (sulfur and HS) and ozone.[4] Ag is the best conductor of heat and electricity and is more malleable and ductile than any other metal except gold. This metal is insoluble in water and in most acids; readily soluble in dilute nitric acid, KCN, in hot concentrated sulfuric acid; it is superficially attacked by HCl.[1] In the presence of air or oxygen, silver solubilizes in fused alkali hydroxides and alkali cyanides.[1] Most silver salts are photosensitive.[1]

Silver Chloride (AgCl)

Silver chloride (m.w. 143.32, d. 5.56, m.p. 455° C, b.p. 1550° C) is a white powder with cubic crystals which exists in nature as the mineral cerargyrite. It is soluble in ammonium hydroxide, sodium thiosulfate potassium cyanide,[9] concentrated sulfuric acid, potassium bromide,[3] concentrated hydrochloric acid, ammonium chloride, mercuric nitrate and silver nitrate[4]; its solubility in water is 0.89 mg/liter at 10° C,[9] 2 mg/liter at 25° C [4] and 21 mg/liter at 100° C[9] ; it is insoluble in alcohol and dilute acids.[4] AgCl darkens upon exposure to light and finally turns black, it exists in several modifications differing in conduct toward light and in solubility in various solvents. AgCl can be melted, cast and fabricated like a metal.[3]

Silver Nitrate ($AgNO_3$)[1,9,3,4]

Silver nitrate (m.w. 169.87, d. 4.352, m.p. 212° C, b.p. (dec) 444° C) is a colorless, transparent, tabular, rhombic, crystalline substance which is odorless and has a bitter, caustic metallic taste and which becomes gray or grayish-black on exposure to light in the presence of organic matter or H_2S regardless of presence or absence of light. $AgNO_3$ is a strong oxidizing agent and caustic. It is soluble in ether, glycerin, hot alcohol, ammonia water, and very slightly soluble in absolute alcohol and acetone. Its solubility in water is 1220 g/liter at 0° C and 9520 at 190° C; the resulting pH of a saturated aqueous solution of $AgNO_3$ is about 6.

Silver Oxide (Ag_2O)

Silver oxide (m.w. 231.74, d. 7.143, m.p. (dec) 300° C) is a heavy, odorless, brown-black cubic powder with a metallic taste which breaks up into its constituents upon exposure to sunlight; moist Ag_2O absorbs carbon dioxide. It is soluble in potassium cyanide solution, ammonium hydroxide, acids; e.g., dilute nitric acid, and sodium thiosulfate solution; it is virtually insoluble in alcohol. The solubility of Ag_2O in water is 13 mg/liter at 20° C and 53 mg/liter at 80° C. Its solubility is pH dependent. As pH decreases solubility increases such that below pH 5, Ag_2O is freely soluble. As pH increases above pH 7 solubility decreases to pH 12, the pH at which Ag_2O is least soluble (0.92 mg/liter). Above pH 12 solubility increases.

Silver Hydroxide (AgOH)

Almost no information is available on the properties of silver hydroxide. Because of its high solubility in water and the preferential formation of Ag_2O (discussed previously), it is virtually nonexistent.

B. Biological Properties

Although the essentially insoluble chloride, bromide, iodide, and oxide of silver are generally non-irritating and relatively benign, some silver salts have been found to be irritating to skin and mucous membranes.[8] The ingestion of corrosive silver nitrate ($AgNO_3$) has been responsible for most cases of acute silver poisoning. The symptoms are those of a severe gastroenteritis and shock, with vertigo, coma, convulsions, and death.[2] Chronic exposure to silver salts may cause argyrism, solely of cosmetic concern.[2] Argyrism is characterized by a greyish-blue discoloration of the skin.

Silver poisoning is treated like acute copper poisoning, except that gastric lavage should be performed with sodium chloride solutions.[2] Apparently BAL has not received a therapeutic trial in acute poisoning. In cases of argyria (result of chronic exposure to silver), BAL has been found not to increase the excretion of silver.[2]

C. Environmental Properties

The water quality standard for silver and its compounds is 0.05 mg/liter as Ag.[6]

From silver ores (Ag_2S, AgCl, etc.) silver ions may be leached into ground waters and surface waters, but since many silver salts such as the chloride, sulfide, phosphate and arsenate are insoluble, silver ions cannot be expected to occur in significant concentration in natural waters.[5]

D. Radioactive Properties

None

Zinc and Its Compounds

A. Physical/Chemical Properties

Zinc (at. wt. 65.37, m.p. 419.4° C, b.p. 907° C, d. 7.14)[9] is a hexagonal crystalline, lustrous, bluish-white metal which is stable in dry air and becomes covered with a white coating of basic carbonate on exposure to moist air. Pure zinc is very slowly attacked by dilute sulfuric or hydrochloric acid; the presence of a small amount of another metal; e.g., copper, tin, lead, accelerates the action of the acids. This metal is slowly soluble in acetic acid and ammonia water; soluble in nitric and readily soluble in solutions of fixed alkali hydroxide with the evolution of hydrogen. Zinc foil will ignite in the presence of moisture.

Zinc Chloride ($ZnCl_2$)

Zinc chloride (m.w. 136.29, d. 2.907, m.p. 290°C, b.p. 732° C[3]) is a deliquescent white granular powder composed of cubic crystals, granules, fused pieces or rods. It is extremely soluble in water (4320.0 g/liter at 25° C, 6150.0 g/liter at 100° C[9]) in dilute concentrations some zinc oxychloride (Zn_2OCl_2) is formed.[1] The pH of a concentrated solution of zinc chloride is approximately 4.0.[1] $ZnCl_2$ is very soluble in dilute hydrochloric acid, alcohol, glycerol and acetone.[1]

Zinc Hydroxide ($Zn(OH)_2$)

Zinc hydroxide (m.w. 99.38, d. 3.053, m.p. (dec) 125° C) is a colorless, rhombic powder which is soluble in acids and alkalies, forming zinc salts and zincates ($HZnO_2^-$; ZnO_2^{--}). The water solubility of this amphoteric compound varies with pH; it is least soluble at pH 9.2 (1.04 mg/liter). Solubility increases as pH increases or decreases from 9.2; at pH 7 its solubility is about 2 g/liter; at pH 5 its solubility is about 1000 g/liter.[9]

B. Biological Properties

Zinc is not inherently a toxic element to man, however, when heated, it evolves a fume of zinc oxide which, when inhaled fresh, can cause a disease known as "brass founders' ague" or "brass chills."[3] It is possible for people to become immune. However, this immunity can be broken by cessation of exposure of only a few days. Zinc oxide dust has also been known to block the ducts of the sebaceous glands and give rise to a popular pustular eczema in men engaged in packing this compound in barrels.[3] Zinc oxide dust which is not freshly formed is virtually innocuous. There is no cumulative effect to the inhalation of zinc fumes. Fatalities, however, have resulted from lung damage caused by the inhalation of high concentrations of zinc chloride fumes.[8]

Soluble salts of zinc have a harsh metallic taste; small doses can cause nausea and vomiting, while larger doses cause violent vomiting and purging.[3] So far as can be determined, the continued administration of zinc salts in small doses has no effect in man except those of disordered digestion and constipation. Another local manifestation of zinc salts is their caustic effect on the skin leading to ulcerations.[8]

Exposure to zinc chloride fumes can cause damage to the mucous membrane of the nasopharynx and respiratory tract and give rise to a pale grey cyanosis.[3] Chloride, because of its caustic action, can also cause ulceration of the fingers, hands and forearms of those who use it as a flux in soldering. This condition has even been observed in men who handle railway ties which have been impregnated with this material. It is the opinion of some who work with it that it is carcinogenic.[8]

The particle size of zinc oxide and zinc chloride is largely responsible for the type and degree of respiratory symptoms and for their differing toxic effects.[8]

It is towards fish and aquatic organisms that zinc exhibits its greatest toxicity.[5] In soft water, concentrations of zinc ranging from 0.1-1.0 mg/liter have been reported to be lethal, but calcium is antagonistic toward such toxicity. Zinc is thought to exert its toxic action by forming insoluble compounds with the mucous that covers the gills, by damage to the gill epithelium, or possibly as an internal poison. The sensitivity of fish to zinc varies with species, age and condition of the fish, as well as with the physical and chemical characteristics of the water. Some acclimatization to the presence of zinc is possible, and survivors from batches of fish subjected to dissolved zinc have been less susceptible to additional toxic concentrations than fish not previously exposed. It has also been observed that the effects of zinc poisoning may not become apparent immediately, so that fish removed from zinc-contaminated tozinc-free water (after 4-6 hours of exposure to zinc) may die 48 hours later.[5]

The presence of copper appears to have a synergistic effect on the toxicity of zinc.[5] The Water Pollution Research Board found that there was little toxic action of zinc precipitated from solution in alkaline water, almost all of the toxicity being attributable to the zinc remaining in solution. They also showed that the toxicity of zinc salts to sticklebacks in soft water is reduced by the addition of calcium carbonate; hence the calcium ion rather than the carbonate ion appears to be the antagonistic factor.[5]

The toxicity of zinc salts is increased at lower concentrations of dissolved oxygen in about the same portion as for lead, copper and phenols; e.g., the lethal concentration at 60% saturation of dissolved oxygen is only about 0.85 that at 100% saturation.[5]

Zinc has a toxic effect towards protozoa and bacteria, but not nearly as pronounced as copper.[5] As little as 0.1 mg/liter of zinc will have an effect upon biochemical oxygen demand and 62.5 mg/liter zinc will cause a 50% drop in the 5-day BOD. In concentrations up to 1.0 mg/liter, zinc is reported to stimulate nitrification, but 10 mg/liter is inhibitory. In very small amounts, zinc has been reported to be dangerous for oysters and in large amounts to impart a blue-green color. Toward snails, toxic action by zinc has been reported at 1.0 mg/liter in natural water and as low as 0.05-0.10 mg/liter in distilled water.[5]

C. Environmental Properties

Many zinc salts (e.g., zinc sulfate and zinc chloride) are highly soluble in water; hence, it is to be expected that zinc might occur in many industrial wastes.[5] On the other hand, zinc salts such as the carbonate, oxide and sulfide, are insoluble in water and consequently it is to be expected that some zinc will precipitate and be removed readily in most natural waters.[5]

One of the problems with heavy metals is their tendency to concentrate through both aquatic and terrestrial food chains.[25] Aquatic macro- and micro-flora and fauna accumulate heavy metals such as zinc in body tissues in significantly greater concentrations than present in the surrounding environment. These organisms are the food source for fish and insects which retain the zinc in the tissues of the consumed organisms. The fish and insects are consumed in turn by larger organisms; this process continues to the organisms at the top of the pyramidal food chain, such as man and large carnivorous birds and mammals. The more links in the chain, the more severe the bioaccumulation phenomenon.

The drinking water quality standard for zinc is 5.0 mg/liter.[6]

D. Radioactive Properties

None

APPENDIX B

PRIVATE WASTE CONTRACTORS AND SERVICE ORGANIZATIONS

A. Large Multi-Site Integrated Hazardous Waste Contractors

Rollins Environmental Services, Inc. P. O. Box 2349 Wilmington, Delaware 19899	Integrated multi-treatment complexes and disposal services; 3 sites
Browning-Ferris Industries, Inc. 300 Fannin Bank Building Houston, Texas 77002	Integrated national treatment and disposal facilities; about 100 sites, mostly landfill but including 5 chemical fixation stations.
Waste Management, Inc. 900 Jorie Boulevard Oak Brook, Illinois 60521	Integrated national treatment and disposal facilities; about 50 sites, mostly landfill.
SGA Services, Inc. 99 High Street Boston, Massachusetts 02109	Integrated national treatment and disposal facilities; about 50 sites, mostly landfill, but with waste treatment subsidiaries.

B. Hazardous Waste Treatment and Recovery Contractors

Chem-Trol Pollution Services Inc. P. O. Box 200 Model City, New York 14107	Liquid treatment and secured landfill disposal.
Hyon Waste Treatment Services Chicago, Illinois 60607	Integrated waste treatment facility, biological, chemical incineration.
Chemical Control Corporation Elizabeth, New Jersey 07207	Liquid and solid chemical processing and incineration.
Conservation Chemical Company P. O. Box 6066 Gary, Indiana 46406	Treatment and disposal of liquid and hazardous wastes.

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Conservation Chemical Company P. O. Box 6304 Kansas City, Missouri 64126	Treatment and disposal of liquid and hazardous wastes.
Industrial Waste Disposal Co. Inc. Dayton, Ohio 45401	Treatment and disposal plant.
Nelson Chemical Company 12345 Schaefer Highway Detroit, Michigan 48227	Wet chemical treatment of cyanides, chrome, plating solutions and similar wastes amenable to this approach.
Evor Phillips Leasing Co. Old Bridge, New Jersey 08857	Industrial liquid transportation and treatment, ocean disposal.
Erieway Pollution Control, Inc. 33 Industry Drive Cleveland, Ohio 44101	Industrial waste treatment and chemical fixation.
Industrial Tank, Inc. 210 Berrellesa Street P. O. Box 831 Martinez, California 94553	Liquid transporting, treatment, and disposal; Class I hazardous waste disposal sites, State of California
Bio-Ecology Systems, Inc. 4100 E. Jefferson Avenue Grand Prairie, Texas 75050	Liquid treatment of metal processing wastes (plating etc.) chemicals, acids, incineration.
Systems Technology Franklin, Ohio 45005	Hazardous waste treatments.
Environmental Waste Control Inc. 26705 Michigan Avenue Inkster, Michigan 48141	Liquid treatment of acids, alkalies, pickle liquor.
Western Processing Company Kent, Washington 98031	Contractor for chemical reclamation.
Pollution Controls, Inc. P. O. Box 238 Shacopee, Minnesota 55379	Incineration and liquid waste treatment.
Pollution Abatement Wastes Oswego, New York 13126	Industrial waste disposal; landfill and incineration

Aztec Mercury P. O. Box 1676 Alvin, Texas 77511	Mercury recovery from industrial wastes.
Wood Ridge Chemical Corp. Division of Troy Chemical Co. Park Place, East Wood Ridge, New Jersey	Reprocessors of mercury wastes.
SGC Industries Old Bridge, New Jersey 08857	Chemical fixation processes.
Renner, Inc. P. O. Box 3224 Port Arthur, Texas 77640	Landfilling and chemical fixation.
Environmental Sciences, Inc. Chemfix Division 505 McNeilly Road Pittsburgh, Pennsylvania 15226	Chemical fixation on-site and off-site mobile treatment units.
George Brodney Brooklyn, New York	Reclaims scrap from lead-acid battery plant.
New Jersey Zinc New York, New York	Reclaims zinc.
Ball Corporation Muncie, Indiana 47320	Reclaims zinc.
Universal Metals & Ore Co. Mount Vernon, New York	Reclaims Ni-Cd cells.
Englehard Industries Newark, New Jersey	Reclaims silver cells.
Handy & Harman New York, New York	Reclaims silver cells.
Mercury Refining Co. Albany, New York	Reclaims mercury cells.
Commercial Metals Company San Francisco, California	Reclaims mercury cells.

Simmons Refining Company Chicago, Illinois	Reclaims mercury cells.
Ventron Corporation Beverly, Massachusetts	Reclaims silver and mercury cells.
Eastern Smelting and Refining Co. Lynn, Massachusetts	Reclaims mercury cells.

C. General Purpose Landfill Contractors and Services

Koski Construction Co. 5841 Woodman Avenue Ashtabula, Ohio 44004	Impervious base settling pond.
Knickerbocker Landfill Malvern, Pennsylvania 19355	Lined landfill.
Pottstown Disposal Services Pottstown, Pennsylvania 19464	Lined landfill.
Scientific Inc. 17 E. Second Street Scotch Plains, New Jersey 07076	Landfill operators accepting liquids.
Sanitas Waste Disposal of Michigan 15500 Schaeffer Road Detroit, Michigan	Contractor for disposal in commercial landfill.
Tork Construction Wisconsin Rapids, Wisconsin 54494	Contractor for disposal in private landfill.
Burgess Brothers Bennington, Vermont	Construction company which operates landfill. Battery wastes encapsulated in steel drums are sent here.
Trashmaster, Inc. Mathews, North Carolina	Landfill.
Harry Rock and Company Cleveland, Ohio	Landfill.

County Line Landfill, Ltd. Fremont, Ohio	Landfill.
Ohio Liquid Waste Disposal, Inc. Fremont, Ohio	Landfill. Leachate collection and treatment.
BFI Waste Systems Kansas City, Missouri	Landfill. Leachate surveillance.

D. General Purpose Secured Landfill Contractors and Services

Nuclear Engineering Co. Inc. Hurstbourne Park 9200 Shelby Road Louisville, Kentucky 40222	Primarily nuclear waste disposal; hazardous containerized waste burial plus some liquid chemical treatment; 3 sites.
Wescon Inc. P. O. Box 564 245 Third Avenue, E. Twin Falls, Iowa 83301	Hazardous wastes secured disposal.
Industrial Hazardous Waste Land Disposal Site Route 2 Lindsay, Oklahoma 74052	Hazardous materials landfill.
Resource Recovery Corporation Pasco, Washington 99301	Interrelated companies - liquid, sludge, and solid hazardous chemical disposal by evaporation plus secured landfill.
Chemical Processors, Inc. 5501 Airport Way, South Seattle, Washington 98108	
County Sanitation Districts of Los Angeles County 2020 W. Beverly Boulevard Los Angeles, California 90057	Municipal Class I disposal sites; State of California
Ventura Regional County Sanitation District 181 S. Ash Street Ventura, California 93001	Municipal Class I disposal site; State of California

APPENDIX C

COST CONVERSION INDICES

Costs for treatment and disposal reported herein were based on mid-1973 pricing. Table C-1 presents applicable indices (or estimates) for converting to December, 1973 dollars. Based on this table, we estimate the average cost increase to be approximately +4% between the two dates. The price increase for particular cost elements (i.e., land, labor, energy, etc.) may be applied individually for those treatment/disposal situations in which the total is particularly influenced by an element which varies significantly from the 4% average. In light of the goal ±25% for most cost estimates, it is not believed necessary for corrections to be made.

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Table C-1. Comparison of Costs, June, 1973 and December, 1973

		Index		
Element	Source	June 1973	Dec. 1973	Change
Construction	C.E. Plant Cost Index	144.5	148.2	+2.6%
	Boeckh Index (Commercial Factory Buildings)	155.3	157.7	+1.0%
Equipment	M & S Equipment Costs	342.9*	349.5**	+1.9%
Energy	Wholesale Price Index (BLS)			
Gas Fuels		128.0	137.6	+7.5%
Electric Power		128.4	135.9	+5.8%
Petroleum Prod., Refined		146.6	252.0	+71.9%
Labor	Avg. Hourly Earnings Current Labor Statistics, (BLS)			
Contract Construction		6.35	6.70	+5.5%
Chemicals & Allied Products		4.46	9.60	+31%
Transportation	No applicable index found	--	--	+5-10% (est.)
Land	Society of Industrial Realtors	--	--	+5%

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*Second quarter

**Fourth quarter

APPENDIX D
EXAMPLE OF COST
ANALYSIS CALCULATIONS

Cost Example for Treatment and Disposal of Calcium Sulfate Sludge from Lead-Acid Battery Producing Using Lime Treatment

A. Basis (Typical Plant)

(1) Amount of Sludge

= 17,300 kkg/yr (19,000 tons/yr) sludge basis

$$= \frac{17{,}300 \text{ kkg/yr}}{1.6 \text{ kkg/cu.m.}} = 10{,}800 \text{ cu.m./yr } (385{,}700 \text{ ft.}^3\text{/yr})$$

(2) Land

$$= \frac{10{,}800 \text{ cu.m.}}{7.62 \text{ m}} = \frac{385{,}700 \text{ cu.ft.}}{25 \text{ ft. (height)}} = 1{,}417 \text{ m}^2 \ (15{,}400 \text{ ft.}^2)$$

= 0.142 ha. (0.35 acre)

B. Level I — Simple On-Site Land Storage

$$\text{(1) Land} = \frac{(0.142 \text{ ha})}{\text{Year}} \times \frac{\$12{,}345}{\text{ha}} = \$1{,}770\text{/yr}$$

(2) Capital

*Front end loader — $10,000 x 1/4 = $ 2,500

*Dump truck — $13,000 x 1/4 = $ 3,250

*Bulldozer — $56,000 x 1/4 = $14,000

$19,750

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*Used for other purposes
Assume 5-yr. life — capital recovery factor = 0.2638 x (19,750) - $5,210

(3) Operating

1/4 man at $8.50/hr on front end loader	
$8.50 x 2 hr/day x 260 day/yr =	$ 4,420
1/4 man at $8.50/hr on truck =	$ 4,420
1/4 man at $8.50/hr on loader =	$ 4,420
supervision 1/4 man at $10/hr =	$ 5,200
Total Labor	$18,460

(4) Energy and Power

Bulldozer 30 gal. fuel/day at 10 hr/wk

Truck — 1 gal/day

Front end loader — 2 gal/day

Total Fuel — 10 gal/day

Fuel cost — $0.40/gal x 10 gal/day x 260 day/yr = $1000/yr

(5) Taxes and Insurance (2% of capital) = $400

(6) Total Annual Costs

Land	$ 1,770
Capital	5,210
Operating	18,860
Energy	1,000
	$26,840

(7) Cost/kkg Product — $\frac{\$26,840}{8,200 \text{ kkg}} = \$3.27$

Cost/kkg Waste — $\frac{\$26,840}{17,300 \text{ kkg}} = \$1.55$

C. Level II — Land Storage With Leachate Collection and Treatment

Assume operating costs for leachate collection and treatment to be neglible as leachate is treated along with plant effluent.

Capital cost for installation of leachate collection system is estimated to be $100,000.

Annual capital recovery cost over ten years is, therefore, $16,280.

Total Annual Costs

Land	$ 1,770
Equipment	5,200
Leachate Collection System	16,280
Operating	18,860
Energy	1,000
Total Cost	$43,110
Cost/kkg Product	$ 5.26
Cost/kkg Waste	$ 2.49

D. Level III(1) — Chemical Fixation (Pilot Study)

Landfill costs are assumed to be the same as Level I.

Chemical fixation cost is contractor estimated to be approximately $3.50/ton

$$\frac{17{,}300 \text{ kkg (wet sludge)}}{\text{Year}} \times \frac{\$3.86}{\text{kkg}} = \$66{,}778/\text{yr}.$$

Level III(2) — Approved Landfill

Operating costs for monitoring is taken at $10,000/yr

Four (4) monitoring wells @ $2,500 ea. = $10,000

Rainwater diversion estimated to be $5.38 sq. m ($0.50/ sq. ft.) (using 30 mil lining material) Approximately 1,860 sq.m. (20,000 sq.ft.) of surface must be covered per year, therefore, annual cost will be $10,000.

Other landfill costs are taken to be identical to those of Level I.

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